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Residential heating, fuelwood demand and tree species: Implications for native forests in the South of Chile

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ABSTRACT

This study compares revealed versus stated household fuelwood preferences for particular tree species, explores the underlying factors, and discusses the implications for native forests. We used a cross-sectional survey of over 550 fuelwood consumers spanning rural areas to small, medium and large cities in the Los Lagos region of Chile conducted in 2020. We employed the Generalized Ordered Logit Model (GOLOGIT) and Multinomial Logit Model of household choice of major tree species for fuelwood. Our results show a significant misalignment between revealed and stated tree species preferences. Household tree species preferences for fuelwood is determined by fuel-value index (FVI), household expenditure, awareness of the relationship between fuelwood production and deforestation, and spatial heterogeneity. Household expenditure, as a proxy of family income, leads to selection of higher FVI tree species, though it is dependent on forest location and accessibility as well. As particular native species are those with high FVI, this implies a possible relationship between household income and native forest degradation that needs to be further explored. At the same time, awareness of deforestation is correlated with households buying the more abundant but less preferred species of fuelwood. These results point to potential impacts on native forests in Southern Chile, which will vary according to tree species ́ecological characteristics, their regeneration potential, and harvesting methods used. Current policies incentivizing better thermal insulation of homes would allow people to use more abundant non-preferred tree species for fuelwood. These findings point to a need for continued research on how improved energy and forestry regulations can support more sustainable fuelwood consumption decisions within local fuelwood markets and better assessments of forest impacts of such policies.

Introduction

Forests supply a wide range of vital ecosystem goods and services that are directly used by humans (fuel, food, timber, and non-timber products, among others) as well as support functions such as balancing the microclimate, carbon sequestration, wildlife habitat, and amenity services (Watson et al., 2018). As of 2019, some 2.6 billion people worldwide depend on fuelwood and other solid fuels for cooking and/or heating (WHO, 2021). However, global forest resources are declining at an alarming rate due to agricultural expansion, growing demands for forest products (Laurance et al., 2014), and natural hazards such as wildfire, pests, and disease. Over the past three decades, there has been considerable debate about fuelwood and its impact on deforestation along with counter-evidence that domestic consumption of fuelwood is not a primary source of forest degradation (e.g. Agarwal, 2021; Arnold et al., 2003; Arnold et al., 2006; Baland et al., 2010; Cooke et al., 2008; Lee et al., 2015). As the primary domestic energy source for the vast majority of households in low and middle-income countries, fuelwood accounts for roughly 50 % of global roundwood production in 2018 (FAO, 2019) and 9 % of global primary energy consumption. Global assessments of the fraction of biomass for domestic cooking/heating that is unsustainably harvested show significant variation depending on geography (Bailis et al., 2015).

Lagging behind the literature on fuelwood and deforestation, however, is more nuanced knowledge surrounding the impact of fuelwood on forest health more broadly (Sassen et al., 2015). Fuelwood extraction

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often does not lead to permanent land-use change (as implied by deforestation), yet it could still result in more subtle forms of forest degradation. However, understanding the potential impact of fuelwood use on forest degradation requires identifying not only the source of biomass for domestic energy but also the specific tree species that are consumed. Yet, there is little evidence connecting household energy decision-making to specific tree species, information that is needed to fully understand the potential ecological effects of fuelwood use on forests.

Household preferences for and consumption of different species for domestic cooking/heating is likely to be influenced by a complex interplay of factors. While species-specific attributes, household socio-economics, and demographic factors have been studied, it has been often in isolation. For example, studies investigating the various socio-demographic determinants of fuelwood consumption in developing countries (e.g. Semenya & Machete, 2019 [South Africa]; Guta, 2014 [Ethiopia]; Egeru, 2014[Uganda]) largely treat "fuelwood" or "wood-fuel" as a general category. These studies and others have seldom incorporated fuelwood species preference and species-specific attributes in estimating household fuelwood demand. However, in reality, it is presumed that households consider and have a preference on what fuelwood species to consume based on their attributes (San et al., 2012). In one study, fuelwood attributes such as the per capita size of fuelwood source (forest area) and tree species compositions were found to be the most important determinants of fuelwood collection source (i.e. among forest reserves, customary forests, and plantation forests), but they did not look into tree species preference specifically (Jumbe & Angelsen, 2011).

Other studies have assessed species-level fuelwood selection (e.g., Tabuti et al., 2003) by linking the selection of particular species to their physical attributes as captured by the Fuel Value Index (FVI) or similar metric. The FVI is computed from various sub-indicators (e.g., energy value, kind and length of flame, moisture, density, ash content, ease of ignition, the flavor of food, and type of smoke produced). These studies assess how these physical aspects of fuelwoods influence household preferred tree species (Ojelel et al., 2015); Chettri & Sharma, 2007 [India], Ramos et al., 2008[Brazil], Timko and Kozak (2016), [Malawi]; Cardoso et al. (2015) [Patagonia]; Marquez-Reynoso et al., 2017 [Mexico]). The FVI was also used for the characterization and identification of tree species for energy plantations in India, where people prefer native species for fuelwood (Sedai et al., 2016). In Brazil and Patagonia Argentina, studies indicated that FVI had a high correlation with the preferred species for fuelwood (Cardoso et al., 2015; Ramos et al., 2008), while others find no relationship between tree species choice and their FVI (Marquez-Reynoso et al., 2017). There is, therefore, mixed evidence regarding relationships between wood energy content and species preference. In addition, most of the studies provide a characterization of the FVI of tree species (Cuvilas et al., 2014; Sedai et al., 2016) or computed simple correlation coefficient to detect the direction of relationships (Cardoso et al., 2015; Marquez-Reynoso et al., 2017; Ramos et al., 2008). As far as we are aware, no empirical research has investigated tree species preference for fuelwood applying a robust econometric model and controlling the FVI alongside other socio-demographic factors.

Addressing the paucity of in-depth quantitative studies on household preferences for fuelwood tree species (despite its importance in driving forest degradation), this study investigates tree-species preferences for fuelwood and factors influencing household choices. We do this by eliciting both stated and revealed preferences of tree species. Stated preferences are based on household survey rankings of species whereas revealed preferences are based on the actual consumption behavior of those same households.

This paper contributes to the literature in two main ways. Firstly, we considered species preference beyond FVI to include household characteristics. As far as we are aware there is no empirical study that has considered FVI and household characteristics jointly in the analysis of tree species preference for fuelwood. Secondly, we investigate for the first time the factors influencing tree species preferences for fuelwood in two steps: 1) revealed preference or choice of particular species categories, 2) alignment of revealed vs. stated preference. Accordingly, this paper analyzes tree species preference by relating it to species-specific attributes (e.g., wood quality, cost, accessibility), as well as socioeconomic and demographic characteristics that both influence household preferences for different tree species for fuelwood. More specifically, in this study, we ask the following questions:

i. What factors influence the choice of tree species households consume?
ii. How do the revealed vs. stated tree species preferences of households align and what are the driving factors?

We examine these questions in Chile, where fuelwood is derived from a mix of species from native forests as well as from Eucalyptus and other exotic species plantations and is largely commercialized (i.e., fuelwood is purchased rather than self-collected). Furthermore, fuelwood consumption levels in southern Chile are largely driven by heating requirements, rather than cooking as is the case in other high-latitude countries (both southern and northern hemispheres) as well as some high-altitude locations elsewhere. This is unlike the context of most research on fuelwood, which is largely concentrated on fuelwood for cooking in low-income settings. This has a number of implications. First, it expands the contexts for understanding fuelwood consumption. Second, the heating requirements and commercial nature result in large purchases of fuelwood making it easier to obtain data on species stated and revealed preferences. Third, the mix of native forest and plantation sources of fuelwood and the high quantities of fuelwood required means that there are major implications for native forest protection with possible lessons to be learned for improved policy.

This remaining part of the paper is organized into six sections. In the follow-up materials and methods section the study area, data, and sampling strategies are described. In the second section, household survey responses concerning tree species preferences for fuelwood are discussed. The conceptual and empirical backgrounds are illustrated in the third section followed by results and discussions. The final section provides the conclusion.

Materials and methods

Study area description

In Chile, fuelwood is primarily used for residential heating, representing the second most important energy source after petroleum. Fuelwood comprises about 25% of the national primary energy consumption (Ministerio de Energía, 2018), which equals about 7.5 million tons of dry matter per year or 104 petajoules. The commercial supply of fuelwood is abundant and commonly transported over one hundred kilometers. As a result, a variety of species are available to consumers. Because the range of available species is not as tied to local forests (as with self-collection) and it is commercially traded, we can more easily distinguish between stated preferences and revealed preferences based on actual purchasing behavior. In the Southern regions of Chile, fuelwood comes primarily from illegal logging of native forests (Reyes et al., 2018), thus underscoring the need to understand the household choice of fuelwood species.

This research was performed in the Los Lagos region of Southern Chile, the region with the highest fuelwood consumption from native forests (Reyes, 2021b). This region is located between 40°13' and 44°03' South latitude, and it is one of the sixteen administrative regions of Chile. This region covers 48,584 km^2 and it is divided into four physiographic units from the Pacific coast to the east: coastal lowlands, coastal range, central valley and Andes range. Southwards, the central valley becomes the sea of Chiloé, which divides the coastal lands from the Andes and creates the Chiloe archipelago and fjords (GORE Los Lagos, 2020). Fig. 1 shows the map of the study area (the Los Lagos region of Southern Chile).

The Los Lagos region has a temperate oceanic climate due to the influence of the Pacific Ocean. Rainfall increases from the coast to the Andes range and can reach between 1600 and 2500 mm per year. Rainfall is distributed throughout the year, although it is more concentrated in winter (GORE Los Lagos, 2021).

Native forests cover 58 % of the region, 23 % is covered by pastures and shrublands, 2 % by tree plantations (mainly *Eucalyptus* sp.), and the remaining 17 % by other land uses (CONAF, 2017). Native forests are the main source of woodfuels and biomass for different uses. Unlike northern regions, the Los Lagos region has a much lower tree plantation cover, and lower agricultural activity, which is oriented to cattle raising, dairy, and the production of potatoes, fodder crops, and cereals.

The Los Lagos region has 828,708 inhabitants, 74 % of them live in urban areas and 26 % in rural areas (INE, 2017). The city of Puerto Montt is the capital, with a population of 220,085 people. This region is divided into four provinces: Osorno (234,122 people) in the north, Llanquihue (408,052) in the central part of the region, Chiloé (168,185) in the south-west (archipelago and fjords), and Palena (18,349) in the south-east (mainly mountains) (INE, 2017). These provinces have different economic bases, as Osorno is oriented to dairy and livestock production, Llanquihue and Chiloé to salmon farming and seafood, and Palena to tourism and small farming.

Data and sampling

Urban area size is the main factor influencing large scale patterns of woodfuel consumption in Chile such as the share of homes consuming it, average per-home consumption, etc. (Ábalos, 1997). Because of this, households were surveyed via a stratified sampling approach by using the classification of the National Statistics Institute (INE, 2017): 1) major cities (between 100,000 and 500,000 inhabitants): conurbation Puerto Montt-Alerce (including La Vara), and Osorno city; 2) large cities (between 40,000 and 100,000 inhabitants): there are no cities in this segment; 3) intermediate cities (between 15,000 and 40,000 inhabitants): Puerto Varas (including Mirador de Puerto Varas), Calbuco, Ancud, Castro, and Quellón; 4) small cities (between 2000 and 15,000 inhabitants) such as San Pablo, Bahia Mansa-Maicolpi, Puerto Octay, Purranque, Corte Alto, Entrelagos, Río Negro, Llanquihue, Los Pellines, Frutillar, Nueva Braunau, Fresia, Los Muermos, Maullín, Carelmapu, Dalcahue, Chonchi, Achao, Quemchi, Queilen, Curaco de Velez, Hornopirén, Futaleufú, Chaitén y Palena; 5) rural areas (towns and

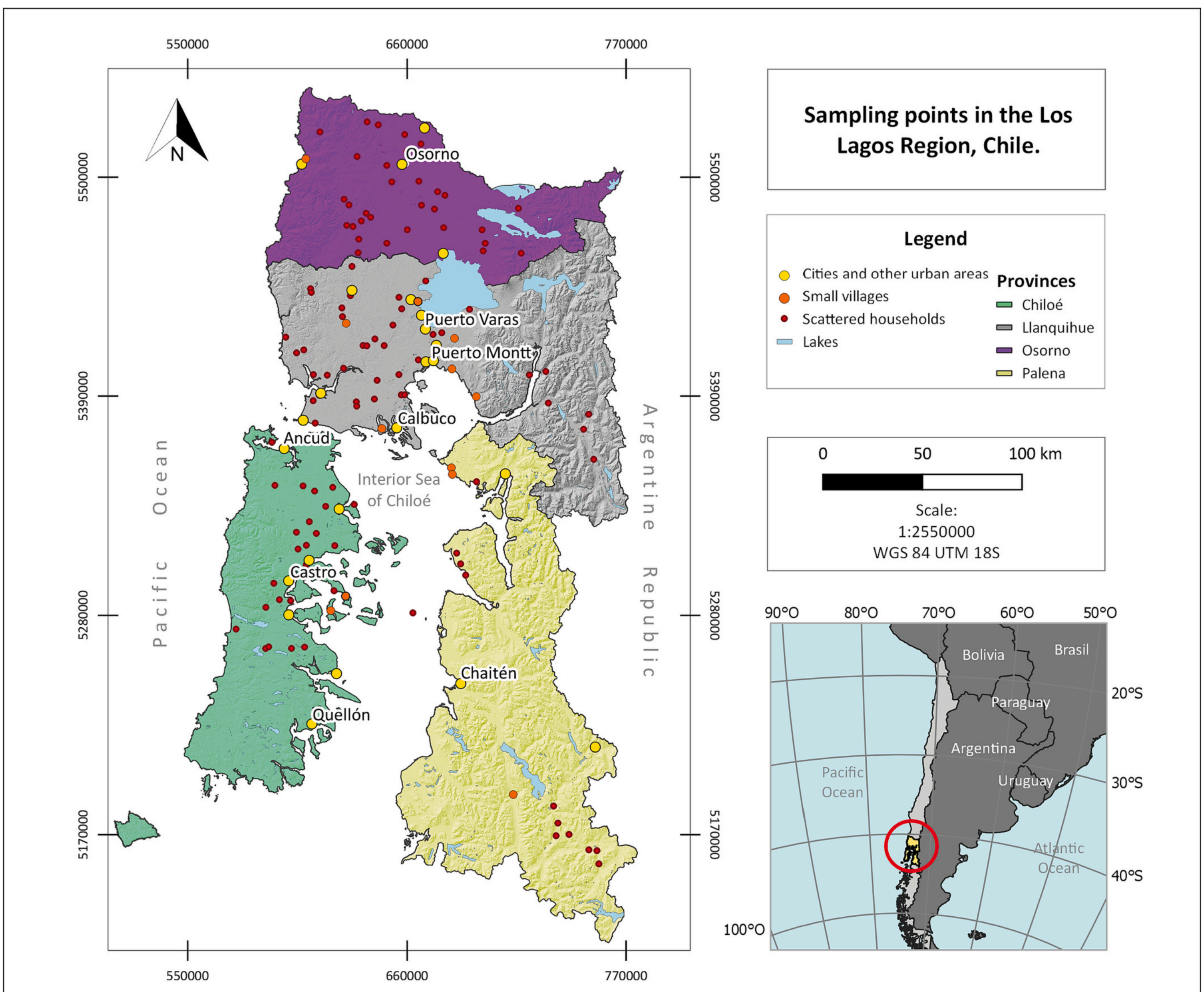

Fig. 1. Study area (Los Lagos region of Southern Chile).

villages smaller than 2000 inhabitants, and dispersed households in the countryside).

The sample size fluctuated between 100 and 142 dwellings per stratum (Table 1), and apartment buildings were not considered because fuelwood is not usually consumed in this segment. The total number of interviewed households was $N = 621$. Households that did not consume fuelwood ($N = 66$) were excluded from the analysis with the remainder ($N = 555$ HHs) retained for the Multinomial Logit Model. Households that didn't state their preferred tree species ($N = 21$) were then excluded from the Generalized Ordered Logit Model. Due to the high dispersion that resulted from allocating sampling in many small cities, a subset (16 out of 25) was randomly chosen in order to concentrate the fieldwork. The selected cities were the following: San Pablo, Puerto Octay, Bahía Mansa-Maicolpi, Llanquihue, Los Pellines, Fresia, Maullín, Carelmapu, Dalcahue, Chonchi, Quemchi, Queilén, Curaco de Vélez, Hornopirén, Futaleufú, and Chaitén. In intermediate and small cities, the sample was distributed depending on the relative size of every city with respect to the total (dwellings city/dwellings stratum).

Description of household fuelwood tree species preference

Stated species preference

In order to elicit the preferred tree species for fuelwood of households we asked an open-ended question: *In your opinion, which are the best species for firewood?* (ranking) where we gave space for households to provide their *1st, 2nd and 3rd ranks for the species. We treat this elicited preference as the household's stated preference.* Respondents stated 32 different tree species and 16 mixes of species they prefer for fuelwood (See Appendix Table A.1 for detail). In Fig. 2, we grouped them into 5 major species and others (i.e., all other species). Our result shows that the three high-value native species (Ulmo, Tepú, and Luma) were predominantly ranked first. Two of these species (Tepu and Luma) along with Hualle, and a mix of other species were ranked second by most households, though Eucalyptus and Ulmo were also identified as second choice species. Ulmo, *broza* (mixture of native species) and other species were ranked third preferred.

Revealed species preference

The species that households "prefer" (stated preference) may not always align with the species that they actually consume. In a separate question, we asked households to identify the tree species the households actually consumed during 2019. This is referred to in this paper as revealed preference. The question we asked was: *What species did you buy or collect in 2019?* We asked households to provide the *species* along with the *amount purchased and the amount collected* (there is a share of wood collection for self-use mostly in rural areas and small towns). Table 2 shows detailed tree species information for species actually consumed by Chilean households alongside their common scientific names and fuel value index. Our result shows that 11 different types of tree species and 9 combinations of those species were consumed for fuelwood in Los Lagos Region of Chile. For one-fifth of the households ($n = 109$, 20 %) who consumed multiple species, we computed the average FVI of species they consumed. Our result shows that the fuel value index of consumed species varied significantly from about 16 (for Álamo = *Populus* sp.) to 46.5 (for Tepú = *Tepualia stipularis*).

The frequency of major tree species consumption by households is given in Appendix Fig. A.1. *Broza*, a mix of native species, was the most frequently consumed tree species or species mix ($n = 262$, 47 %). About 24 % of the households consumed eucalyptus (Eucalyptus sp), an exotic tree that is not native to Chile and grown on plantations. Three high-value native species (Ulmo, Tepú and Luma) were consumed by 14 %, 12 %, 11 % of households, respectively (percentages do not add to 100 % as households sometimes purchased a mix of different specific species).

Misalignment of revealed and stated preferences

It is important to understand the degree to which revealed preference aligns with stated species preference. It serves as an indicator of the degree to which the household's fuelwood demand is satisfied from their stated species preference. Our finding shows a significant misalignment between the two. The details for revealed vs. stated preference of the most commonly consumed species is presented in Fig. 3. The binary alignment/non-alignment of revealed and stated preference shows that out of the households who stated their preferred species ($n = 534$), about ($n = 197$, 35 %) did not consume any of their preferred species. Our finding also shows 4 % did not state their preferred species (DSP). Our finding shows that almost all consumers of luma-tepú about 12 % (overall sample) and ulmo-hualle about 11 % (overall sample) stated that they were highly preferred species. Regarding Eucalyptus, the majority of the consumers (about 11 % of the overall sample) stated it was a less preferred species while about 5 % (overall sample) and 3 % (overall sample) respectively stated it was a non-preferred and highly preferred species. In contrast, a larger proportion (28 % [overall sample]) of other species consumers stated that it was as a non-preferred species, while 11 % and 8 % (overall sample) of the consumers respectively stated that other species groups were less preferred and highly preferred tree species. Altogether, this shows a significant misalignment between revealed and stated preferences as over one-third of the households didn't consume their preferred species.

Conceptual and empirical framework

The standard economic theory to model household choice behavior is the random utility maximization framework (McFadden, 1974). According to this theory, the underlying reason for the choice of a specific alternative over the rest is primarily dependent on the principle of a rational consumer maximizing utility. Household choice of tree species and the alignment of revealed and stated species preference is therefore based on rational decision-making considerations wherein they maximize utility given a set of constraints.

Household choice behavior is presumed to be conditioned by a set of resource endowments, demographic factors, attributes of species (e.g., cost, availability, quality), and other socio-cultural and ecological factors. The accessibility of species in terms of physical accessibility (local accessibility of the species) and economic affordability (cost) are important considerations.[1] The spatial factors are key considerations in studying household species preference for fuelwood because species distribution varies across geographical spatialities, specially when fuelwood is collected. Household's awareness about whether fuelwood causes pressure on forests is also expected to be an important factor influencing species choice decision. A study in Greece indicated a positive relationship of pro-environmental attitude (that depends on individual's socio-demographic characteristics) and fuelwood consumption as a renewable energy (Arabatzis & Malesios, 2013).

While the literature on fuel quality relates physical aspects of the fuel to household choice, there is a much larger literature that is focused on investigating how socioeconomic factors influence household fuelwood consumption but without differentiating between type of fuelwood consumed. Studies have indicated that fuelwood use is influenced by the level of household income and education of the head, and family size (de Arruda et al., 2019; Egeru, 2014; Guta, 2014; Semenya & Machete,

[1] Price and/or distance to fuelwood sources are generally relevant factors that determine household fuelwood consumption behavior and preference for tree species. However, we didn't control these variables in our analysis due to a lack of reliable information. Our survey covered all spatialities. Distance is less relevant and not visible to survey respondents in urban areas. At the same time, price is not available for those in rural and small/medium cities where households may collect fuelwood and/or markets are less formalized.

Table 1
Sample distribution in the Los Lagos region.

Large cities				Intermediate cities		Small cities		Rural areas	
County	N	County	N	County	N	County	N	County	N
Pto. Montt	119	Osorno	100	Pto. Varas	28	San Pablo	9	Pto. Montt	25
				Calbuco	15	Pto. Octay	4	Osorno	5
				Ancud	27	Bahía Mansa	2	Pto. Varas	4
				Castro	33	Llanquihue	27	Pto. Octay	4
				Quellón	17	Los Pellines	2	Palena	7
						Fresia	14	Purranque	3
						Maullín	7	Puyehue	1
						Carelmapu	5	Quemchi	3
						Dalcahue	15	Quinchao	2
						Chonchi	11	Río Negro	7
						Quemchi	5	San Juan C.	5
						Queilén	6	San Pablo	4
						Curaco de V.	2	Ancud	5
						Hornopirén	13	Calbuco	3
						Futaleufú	9	Chaitén	2
						Chaitén	9	Chonchi	11
								Cochamó	6
								Dalcahue	8
								Fresia	6
								Frutillar	1
								Hualaihue	9
								Llanquihue	4
								Los Muer.	12
								Maullín	5
Total	119		100		120		140		142

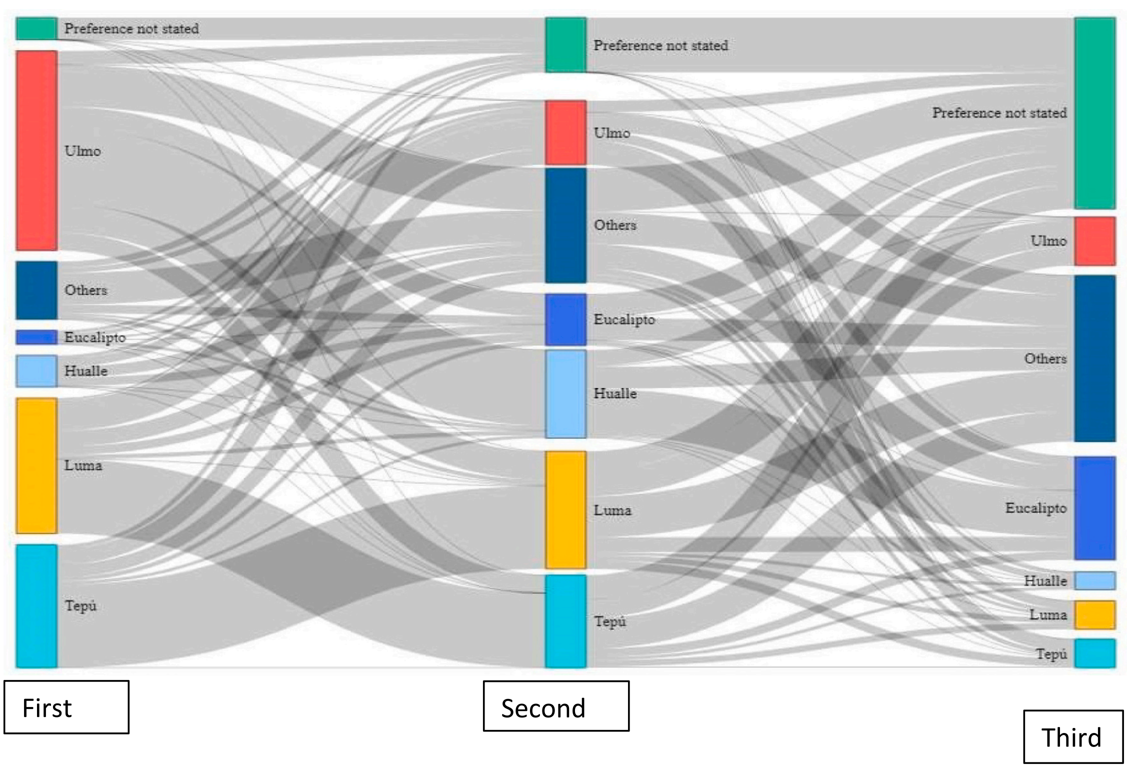

Fig. 2. Distribution of households by stated (elicited) tree species preferences by ranked/order of most preferred (first) to least preferred (third).

2019). The quality of wood or energetic density of fuelwood was found to be an important factor in consumers' preference for domestic eucalyptus for fuelwood in Italy (Palmieri et al., 2020). Availability of species and fuelwood quality were considered important in the community selection of tree species for fuelwood but species with high FVI were not always preferred/selected (Sahoo et al., 2014).

In response to a stove intervention, households responded differently depending on the mix and availability of forest vs. farm biomass (Singh et al., 2018). Improved cookstove influences the preference for tree species for wood whereby households that had the stove choose slowly-growing native species (Timko & Kozak, 2016). The size of private garden, heating hours, and elevation positively influence fuelwood consumption, while education and access to electricity were found to reduce it (Mislimshoeva et al., 2014). Household use of multipurpose tree species and shrubs was found to be influenced by gender, type of occupation and education level (Kisangau et al., 2021).

Table 2
Scientific name and Fuel Value Index of tree species consumed (revealed preference).

S/N	Species	Scientific name	Fuel Value Index (FVI)
1	Broza	Mix of native woods	23.4
2	Broza, Eucalipto	Mix	24.3
3	Canelo	*Drimys winteri*	20.3
4	Coigue	*Nothofagus dombeyi*	23.1
5	Eucalipto	*Eucalyptus* sp	25.3
6	Hualle	*Nothofagus obliqua*	22.9
7	Hualle, Canelo, Eucalipto	Mix	22.8
8	Luma	*Amomyrtus luma*	36.0
9	Luma, Tepú, Brosa	Mix	35.3
10	Luma-ulmo	Mix	30.6
11	Pino	*Pinus radiata*	18.2
12	Tepú	*Tepualia stipularis*	46.5
13	Tepú, Luma, Ulmo	Mix	35.9
14	Tepú-Luma	Mix	41.3
15	Tepú-Ulmo	Mix	35.9
16	Ulmo	*Eucryphia cordifolia*	25.2
17	Ulmo, Eucalipto	Mix	25.2
18	Álamo	*Populus* sp.	15.9
19	Coigue-Hualle	Mix	23.0
20	Mañio hembra	*Saxegothaea conspicua*	26.6
21	Coigüe de Chiloé	*Nothofagus nitida*	25.3
22	Mañío macho	*Podocarpus nubigena*	25.0
23	Tepa	*Laurelipsis philippiana*	20.4
24	Frutales	Mix of fruit trees	30.7

Note: Based on Lobos (2005). FVI is estimated from higher heating values, timber densities and assuming a water content of 33 % (Fibre saturation point). Broza represents the average fuel value index of *Saxegothaea conspicua*, *Nothofagus nitida*, *Podocarpus nubigena*, *Nothofagus dombeyi*, *Laurelipsis philippiana*, and *Drimys winteri* (Valdivian rainforests). The category Broza-Eucalipto is estimated including Eucalipto in the previous calculation.

In central-southern Chile a study indicated that households main heating fuel choice is primarily driven by socioeconomic factors and dwelling characteristics (Jaime, 2020; Schueftan & González, 2013). Another study on certified firewood purchase in Temuco and Padre Las Casas, Southern Chile also indicated that household's purchasing behavior is dictated by factors such as income level, availability, presence of older adults at home, price, convenience and psycho-social variables such as their knowledge of and the amount of attention they pay to air quality (Boso et al., 2021).

In Brazil, the transition from fuelwood to LPG for cooking follows a consistent pattern, and is influenced by accessibility, affordability and the convenience of the fuel (Teixeira et al., 2018). In India, Malakar and Day (2020) show this transition is challenging due to cultural barriers, although the subjective perception of well-being that underlies energy use can change after the adoption of new fuels. In Chile, the use of LPG for cooking is extensive, even in the countryside. However, energy demand for heating remains a challenge. Several authors (Reyes et al., 2015; Schueftan & González, 2013) have mentioned that the amount of energy that is needed for heating homes is such, that people cannot afford energy sources other than fuelwood, which is between 3 and 5 times cheaper than LPG, kerosene and electricity. As can be seen from just these examples, context is important in considering household energy transitions.

Empirical approach

Construction of dependent variables

We used two distinct modeling approaches to address each of our objectives. To address question 1, we applied the Multinomial Logit Model to investigate factors influencing the choice of main species consumed (revealed preference). The Multinomial Logit Model treats the dependent variable as a set of categories but makes no assumptions regarding the ordering of those categories. Accordingly, recategorization is needed because modeling each of the 20 different species consumed by households is infeasible. We based our categorization on ecological differences among species. Eucalyptus is an exotic tree, which is planted to produce cellulose, but it can be also sold as fuelwood. *Amomyrtus luma* (Luma) and *Tepualia stipularis* (Tepú) are more common in rainforests and peatlands within the region, and they are shade-tolerant species, while *Eucryphia cordifolia* (Ulmo) and *Nothofagus obliqua* (Hualle) are more frequent in the central valley and drier zones (deep soils; shade-intolerant and intermediate shade-tolerant species).

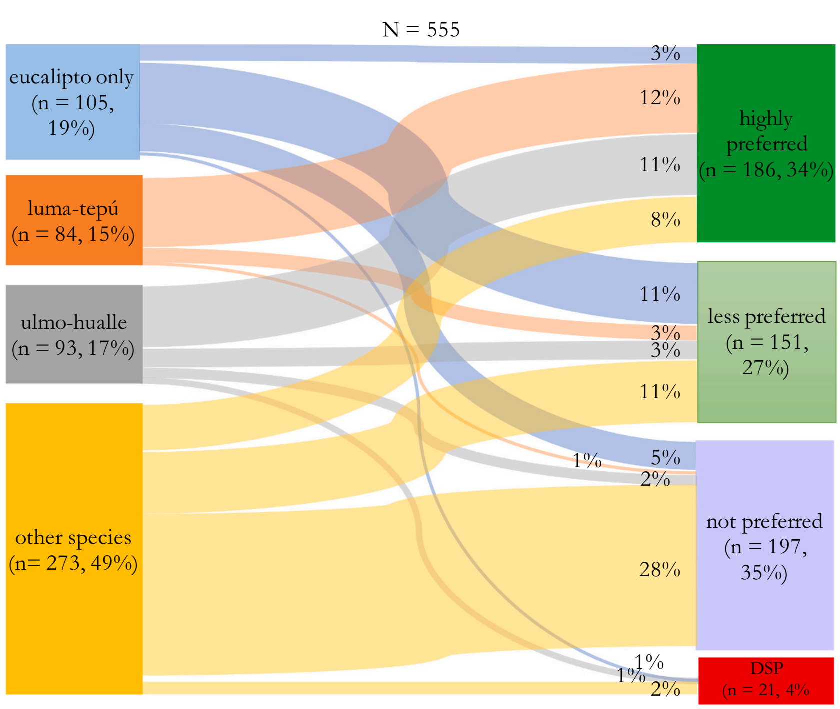

Fig. 3. Distribution of households by revealed vs. stated preferences for major tree species categories.

Mixed species is a group of several native species present in native forests but are less valuable for fuelwood. They are usually named "*broza*" by local people. For simplicity, we generated a dependent variable that takes four values (= 1 if household choose Eucaliptos only; = 2 if household consumed either luma or tepú, or both only; = 3 if household consumed ulmo or hualle, or both only; and = 4 if household consumed any other species).

To address question 2, we applied the Generalized Ordered Logit Model (GOLOGIT) to examine the factors associated with the consumption of preferred species (in the ranking). The dependent variable is ordinal as it represents the alignment of revealed vs. stated species preference. It takes the highest value if the household consumed its first stated preference. Accordingly, the dependent variable can take on three values (=3, if the household consumed the first preferred species (named *highly preferred species*), = 2, if the household consumed the second and or third preferred species (*less preferred species*), and = 1, if the household consumed only *non-preferred species*)). Additionally, in the case where HHs consume a mix of two or three different types of species and they stated their preference we categorized them under the highest possible rank.[2] The decision to collapse the second and third preferred species into one group was made after testing the generalized ordered logit. We found that the model fails to converge due to predicted negative probabilities for many observations (n = 223, 42 %). To address this problem, we clubbed the second and the third-ranked species together under less preferred species.

The descriptive statistics of the dependent variables are presented in Table 3. Nearly one-fifth (19 %) of the households consumed eucalyptus exclusively while nearly half (49 %) consumed "other native species" (*broza*). The remaining 17 % and 15 % consumed either or both luma and tepú, and ulmo and hualle, respectively. Our result shows that of the households who stated their preference (n = 534) about 63 % consumed a preferred tree species while the remaining 37 % did not consume what they preferred. Of those who consumed species of their preference about 35 % (overall sample) consumed their most preferred (first ranked species) while about 28 % consumed less preferred species (species ranked as second or third or both).

The Multinomial Logit Model

The multinomial logit model (question 1) was applied to analyze factors associated with household choice of main tree species consumed or tree species choice. The multinomial logit model has been extensively applied in the literature (see Green, 2012; McFadden, 1974). Households are assumed to choose the tree species that gives them the maximum utility from the four alternatives. Suppose that household (i = 1, 2, …, N) face a choice among j alternative species (j = 1 = eucalipto only, 2 = luma-tepú, 3 = ulmo-hualle, 4 = other species) used for firewood. Let U_{ij} denotes the utility that household i derive from alternative j. As rational consumer households are expected to choose alternative j if and only if $U_{ij} > U_{ik}$.

Suppose that P_{ij} (j = 1,2,3,4) stands for the probability associated with a given category of tree species choice. In general, the probability of choosing a specific category of species is specified as:

$$P_{ij/j\neq 1} = pr(Y_i = j/j \neq 1) = \frac{exp(X_i\beta_j)}{1+\sum_{j=1}^{4} exp(X_i\beta_j)}, j = 2,3,4 \tag{1}$$

For the reference group it is specified as:

$$P_{i1} = pr(Y_i = 1) = \frac{exp(X_i\beta_j)}{\sum_{j=1}^{4} exp(X_i\beta_j)} \tag{2}$$

Generalized Ordered Logit Model

The Generalized Ordered Logit Model (GOLOGIT) was applied to address question 2. Given the nature of the dependent variable (a ranked indicator of the alignment of revealed preferences with the ranking of stated species preference), an ordered choice model is an appropriate approach.

The ordered logit model (OLOGIT) or proportional odds model is commonly used for such dependent variables. However, a violation of the assumption of proportional odds due to a fixed threshold can yield biased and inconsistent estimates resulting from misspecification of the distribution (Eluru, 2013; Johnston et al., 2020; Williams, 2006). As described in the results section we tested and detected violation of the parallel assumption of proportional odds, showing OLOGIT yields a biased estimate.

One alternative that some researchers employ is to continue to use the model but acknowledge the problem and the bias it can introduce. Another approach that has been taken is to use a Multinomial Logit Model that does not include the ordering of the dependent variable. This can solve the bias problem but is less parsimonious, can be complex to interpret, and often does not use valuable information on the ordering of categories (Williams, 2016).

More recently an increasing number of studies have switched towards the GOLOGIT model. The GOLOGIT model relaxes the restrictive assumption of a fixed threshold and thus provides a more flexible approach by specifying the threshold parameter as a linear function of exogenous variables (Eluru, 2013). It is less restrictive than the ordered logit model while being more parsimonious than the Ordered logit and hence yields superior results (Williams, 2016).

We applied the GOLOGIT model to understand the influence of factors determining household preferred tree species choice (i.e., alignment or misalignment of revealed and stated preference). The model is based on the maximum likelihood estimation approach.

The probability of alignment for the given stated preference level can be specified as:

$$P(Y > j) = \frac{exp(\alpha_j + X_i\beta_j)}{1 + exp(\alpha_j + X_i\beta_j)}, j = 1, 2 \tag{3}$$

Where $P(Y > j)$ stands for the cumulative probabilities of alignment of revealed species within the ranking of stated species preference, $j = 1, 2$, 3 represent the ranking of stated species preference at which revealed and stated preferences aligned, $\alpha_j \& \beta_j$, and X_i represent respectively the vector of parameters to be estimated and the vector of observed explanatory variables in the model.

To address the problem arising from the violation of the proportional odds assumption by some variables in the model (Michalaki et al., 2015)

Table 3
Frequency of households by tree species preferences.

Dependent variable	Species category	Freq.	Percent
	eucalipto only (= 1)	105	18.92
Main species category consumed (revealed preference or tree species choice)	luma-tepú (= 2)	84	15.14
	ulmo-hualle (= 3)	93	16.76
	other species (= 4)	273	49.19
Ranked alignment of revealed with stated preference (preferred tree species choice)	Non preferred species (= 1)	197	36.89
	Less preferred species (= 2)	151	28.28
	Highly preferred species (= 3)	186	34.83

[2] Those HHs that consumed first and second preference species at the same time (N = 35 HHs), those who consumed first and third simultaneously (N = 30), and those who consumed first, second and third simultaneously (N = 30) were grouped under first (category 3). Those who mix the second and third preference (N = 18) were grouped under the second (group 2).

studies have applied gamma parameterized GOLOGIT or more commonly named partially constrained or proportional odd model (Peterson & Harrell Jr, 1990). Following previous studies (Aidoo & Ackaah, 2019; Kaplan & Prato, 2012; Wang & Abdel-Aty, 2008) the gamma parameterized or partially constrained model can be specified as:

$$P(Y_i > j) = \frac{exp\left(\alpha_j + X_{1i}\beta_1 + X_{2i}\beta_2 + X_{3i}\beta_{3j}\right)}{1 + exp\left(\alpha_j + X_{2i}\beta_2 + X_{3i}\beta_{3j}\right)} \quad (4)$$

where X_{3i} stands for the vector of sub explanatory variables in the model for which the proportional odds assumption is violated and β_{3j} stands for the vector of corresponding parameters which are free to differ but the $\beta_1 \& \beta_2$ other the same for all values of j and the model is estimated by maximum likelihood (Williams, 2006).

The GOLOGIT model yields J-1 column of coefficients of cumulative logit model results, where J is the number of categories (in our case tree species preference ranks). The first panel contrasts category 1 with categories 2, 3; the second panel contrasts categories 1 and 2 with categories 3. Accordingly, positive estimated results show a higher likelihood of being in a higher category of Y than the current one as the explanatory variable increases, whereas negative results indicate a higher likelihood of being in the current or a lower category as the explanatory variable increases (Williams, 2016). Thus, positive coefficients mean that higher values on the covariates make higher values on the dependent variable more likely. Our discussion focuses on estimating the Marginal Effects (ME) which are straightforward and useful interpretations of the variables (Wang & Abdel-Aty, 2008; Williams, 2016).

Identification of covariates controlled in the model

Based on the review of previous studies we considered six categories of explanatory variables in our model (see Table 4 for a detailed description). These include: i) species-specific characteristics (FVI of consumed species), ii) household and decision-maker-specific characteristics (head's gender, age, and education, family size and aggregate expenditure), iii) residential characteristics (year of construction, size, length lived in the residence), iv) household consideration of the attributes (wood quality, cost, accessibility) of tree species they consumed in large quantity, v) household perception on deforestation, and vi) spatial heterogeneity (province and urban-rural gradient). We computed the FVI of tree species consumed by households based on a previous study (Vega-Nieva et al., 2015) and we assumed 33.3 % water content.

In our survey, Likert scales were used to capture the responses to questions of deforestation perception and fuelwood consumption. The responses were recoded as: strongly agree, agree, neutral, disagree, strongly disagree, and "I don't know" options. To reduce the dummy variable trap, we grouped the responses into three groups: agree, neutral and disagree. Since the response "I don't know" was difficult to analyze we grouped it together with the "neutral" group. For comparison, we fit a GOLOGIT model (See Appendix Table A.2) where we dropped the deforestation perception variables. Our result shows that the estimated coefficients for other covariates were more or less similar.

Table 4
Summary statistics of explanatory variables used in the models.

Variables	Overall	Non-preferred	Preferred	Diff
Species specific characteristics				
FVI	27.41 (0.28)	24.77	29.03	4.26****
HH variables				
Household size (# of HH family members)	3.32(0.06)	3.24	3.36	0.12
Expenditure (HH monthly expenditure (Ch pesos/month))	469,418 (11003)	450,508	480,506	29998*
Decision maker characteristics				
Age of decision maker (years)	54.14 (0.65)	54.88	53.7	−1.18
Decision maker's gender (1/0)	0.51(0.02)	0.58	0.48	−0.1**
Decision maker's below high school (1/0)	0.40(0.02)	0.48	0.35	−0.13****
Decision maker's high school(1/0)	0.38(0.02)	0.31	0.41	0.1**
Decision maker's above high school(1/0)	0.22(0.02)	0.21	0.23	0.02
Dwelling characteristics				
Size of dwelling area (sq. m)	92.78 (2.56)	94.84	91.57	−3.27
Started living before 1990 (1/0)	0.22(0.02)	0.22	0.22	0
Started living -during 1990 to 2010(1/0)	0.38(0.02)	0.36	0.39	0.03
Started living since 2010 (1/0)	0.40(0.02)	0.42	0.39	−0.03
Household consideration of species they consume in large quantity				
Quality (1/0)	0.36(0.02)	0.32	0.38	0.06*
cost (1/0)	0.34(0.02)	0.29	0.36	0.07**
Accessibility (1/0)	0.23(0.02)	0.27	0.21	−0.06*
Others(1/0)	0.058 (0.01)	0.056	0.06	0.004
Awareness about deforestation				
Defor. in the county(agree) (1/0)	0.75(0.02)	0.73	0.76	0.03
Defor. in the county (disagree) (1/0)	0.22(0.41)	0.24	0.21	−0.03
Defor. in the county (neutral) (1/0)	0.13(0.33)	0.14	0.12	−0.02
Fuelwood cause defor. (agree) (1/0)	0.65(0.02)	0.61	0.67	0.06*
Fuelwood cause defor. (disagree) (1/0)	0.15(0.35)	0.18	0.13	−0.05*
Fuelwood cause defor. (neutral) (1/0)	0.10(0.30)	0.09	0.11	0.02
Provincial fixed effect				
Province –Llanquihue and Chiloé (1/0)	0.68 (0.02)	0.70	0.67	−0.03
Province -Osorno (1/0)	0.23(0.42)	0.17	0.27	0.1***
Province -Palena (1/0)	0.09(0.28)	0.12	0.06	−0.06***
Spatial strata				
Large city -Puerto Montt (1/0)	0.16 (0.37)	0.19	0.14	−0.05
Large city – Osorno (1/0)	0.15(0.36)	0.07	0.20	0.13****
Medium cities (1/0)	0.19(0.39)	0.13	0.23	0.1****
Small cities (1/0)	0.25(0.43)	0.27	0.23	−0.04
Rural (1/0)	0.25(0.43)	0.34	0.20	−0.14****
N	*534*	*197*	*337*	

Note: proportions are within each group. Standard deviation in parenthesis * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$. The variables that are Bold show statistically significant variation.

Results

Descriptive analysis of key variables

Fuelwood is consumed by homes for both heating and cooking, although heating is by far the use that demands more energy (kWh per year). In urban areas, 85 % of households consume fuelwood; 53 % just for heating, 27 % for heating and cooking, and 5 % just for cooking; while in rural areas 99 % of homes consume fuelwood, 85 % for heating and cooking, and 14 % just for heating. Families that cook with fuelwood commonly use a widely used model of cooking stoves without airflow control. This means they cannot control the burn rate, embers cannot be maintained for long periods, and stoves have to be frequently re-fueled. By contrast, families that consume fuelwood just for heating (14 % in rural areas and 57 % in urban areas) have stoves that are able to control the burning rate (stoves with mechanisms to regulate the airflow). The result is that in most rural households, the lack of burn rate control means keeping embers is not possible while in urban areas people have a higher control on the combustion process and embers are a key factor in maintaining heat in their homes.

Table 4 presents the descriptive statistics of explanatory variables considered in the empirical models and the mean difference between households who consumed preferred and non-preferred tree species for fuelwood in Chile.

There were a number of key differences between households that consumed their preferred species and those that did not. As it was expected, households consuming their preferred species were better off economically than those that did not consume their preferred species, and the difference was statistically significant ($p < 0.1$). A larger proportion of non-preferred species consumers had decision makers with schooling below high school, and the variation was statistically different ($p < 0.001$). A larger proportion of non-preferred species consumers had male decision-makers and the variation was statistically significant ($p < 0.05$).

Households consuming their preferred species consumed tree species with a higher FVI (29) than those who consumed non-preferred species (25), and the variation was statistically significant ($p < 0.001$). A higher proportion of non-preferred species consumers (18 %) agreed that fuelwood causes deforestation while relatively lower (13 %) preferred species consumers had the awareness.

The spatial differences along the urban-rural gradient show statistically significant variation. About 20 % of preferred species consumers were residents of the large city of Osorno while only 7 % of non-preferred species consumers lived in this city. Similarly, about 23 % of preferred species consumers lived in medium cities as compared to 13 % of non-preferred species consumers. In contrast, a higher proportion (34 %) of non-preferred species consumers were rural residents as compared to 20 % of preferred species consumers. In all cases, the variations were statistically significant ($p < 0.001$). Our result also shows significant provincial variation in the distribution of the two groups of households. In the Osorno province, a higher proportion (27 %) were preferred species consumers compared to (17 %) non-preferred species consumers. By contrast, in the Palena province, a higher proportion (12 %) were non-preferred species consumers compared to only 6 % of preferred species consumers. Variations were statistically significant ($p < 0.01$) in both.

Factors influencing tree species choice

The estimated multinomial logit model results of the factors associated with tree species consumed by households for fuelwood (revealed preferences) are presented in Appendix Table A.3. Our discussion focuses on the Marginal Effects which were computed using STATA command margins after mlogit (See Table 5). The likelihood ratio test of the overall model shows that the explanatory variables were jointly statistically significant ($P < 0.001$).

Our finding shows the inevitable and prevalent pressure that fuelwood consumption poses on high-value native species. The likelihood of choosing Luma-Tepú species and other species over eucalyptus alone is positively associated with the FVI of the species. This shows that

Table 5
Marginal effect of multinomial logit model results of the determinants of main tree species choice for fuelwood by Chilean households.

Explanatory variables	Species categories							
	Eucalyptus only		luma-tepú		Ulmo-Hualle		Others	
	ME[‡]	SE	ME[‡]	SE	ME[‡]	SE	ME[‡]	SE
Fuel value index	−0.005****	0.001	0.004****	0.001	0.0005	0.001	0.0005	0.001
Expenditure (log)	−0.025	0.026	−0.002	0.024	−0.011	0.027	0.036	0.034
Size of dwelling area (log)	0.062**	0.028	−0.004	0.026	0.026	0.028	−0.084**	0.036
Started living (during 1990 to 2010)[a]	0.003	0.042	−0.007	0.039	−0.015	0.041	0.019	0.055
Started living (since 2010)[a]	−0.003	0.047	−0.019	0.041	−0.034	0.045	0.056	0.059
Dec.maker's age	−0.002*	0.001	−0.002	0.001	0.003**	0.001	0.001	0.002
Dec.maker's gender	−0.024	0.03	−0.045*	0.027	−0.001	0.031	0.069*	0.039
Dec.maker high school [b]	−0.054	0.038	−0.011	0.034	0.172****	0.041	−0.106**	0.048
Dec.maker's above high school[b]	−0.014	0.043	−0.025	0.04	0.169****	0.046	−0.129**	0.056
Household size	0.013	0.01	−0.022***	0.01	0.001	0.011	0.008	0.014
Quality	0.017	0.038	−0.001	0.032	0.027	0.038	−0.043	0.047
cost	0.053	0.038	−0.01	0.034	0.018	0.039	−0.062	0.048
Accessibility	−0.004	0.042	0.042	0.037	0.02	0.044	−0.058	0.052
Others	−0.009	0.062	−0.087	0.082	0.042	0.069	0.053	0.092
Deforestation in county (neutral)[c]	−0.011	0.059	−0.104*	0.064	0.062	0.057	0.053	0.08
Deforestation in county (disagree)[c]	−0.037	0.064	0.026	0.059	−0.029	0.06	0.04	0.08
Fuelwood cause deforestation (netural)[d]	−0.073	0.067	−0.076	0.063	0.053	0.058	0.096	0.082
Fuelwood cause deforestation (disagree)[d]	−0.007	0.06	0.103*	0.057	0.004	0.058	−0.1	0.078
Province -Osorno[e]	0.039	0.075	0.097*	0.053	−0.263****	0.127	0.127	0.092
Province Palena[e]	−0.07	0.07	0.011	0.058	−0.011	0.064	0.07	0.075
Large city - Puerto Montt[f]	0.069	0.048	0.135****	0.048	−0.003	0.053	−0.201****	0.064
Large city - Osorno[f]	0.319	8.737	−1.463	82.65	0.625	12.518	0.518	61.396
Medium cities[f]	−0.324****	0.125	0.201****	0.045	0.038	0.072	0.086	0.089
Small cities[f]	−0.036	0.052	0.046	0.045	0.039	0.052	−0.048	0.06

Note: Base category Eucalipto only.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.
‡ The average marginal effects and their *p*-values were obtained by the margins command in Stata.
[a] Refernce group before 1990.
[b] Reference group no education or primary school.
[c] Refernce group neutral about deforestation in your county.
[d] Reference group neutral about fuelwood cause deforestation.
[e] Reference group Llanquihue and Chiloé.
[f] Reference group was rural.

households prefer to consume species with a high FVI. This confirms the theory outlined above that, as rational consumers, households are inclined to consume species with a high FVI that yields maximum utility in terms of heating.

Our finding shows the likelihood of choosing luma-tepú and other species as compared to eucalyptus only tends to decrease with an increase in the size of the dwelling area (larger homes tend to chose eucalyptus in comparison smaller ones). Household family size had an expected negative influence on the choice of high-value native species. Our finding indicates that with an increase in the family size, the likelihood of choosing these species as compared to eucalyptus tends to decrease. Our result also indicates that the age of the decision maker is associated with a higher likelihood of choosing Ulmo-Hualle compared to eucalyptus alone.

The education level of the household's decision-maker was found to be the key factor in the household choice of high value native species, especially the Ulmo-Hualle species category. The probability of consuming Ulmo-Hualle was on average 17.2 % and 16.9 % higher for households with a decision maker who attended high school and above high school, respectively, than those with a decision maker who was illiterate or attended elementary school (see Table 5).

In urban areas, fuelwood is mainly used for heating in stoves where people can control burning rate by opening/closing the air intake (control of the airflow), which implies a higher valuation of embers (Amigo, 2019, p. 81) (Ulmo and Hualle produce abundant embers). By contrast, in rural areas, people prefer cheaper fuelwood, like Eucalyptus, as they consume larger volumes in lower efficiency cooking stoves, and fuelwood is also for both heating and cooking. In these cases, the presence of embers is less relevant, as most people cannot control the burning rate.

Disagreeing about fuelwood causes deforestation is associated with a 10.3 % higher probability of choosing luma-tepú compared to agreeing. This shows that the level of consumers ́ awareness about the impact of fuelwood consumption is associated with the utilization of high-value native species like Ulmo, Luma and Tepú.

Our results also show a significant spatial dimension along the urban-rural gradient of household tree species choice for fuelwood. The spatial heterogeneity captures population density and the consequent size of the fuelwood market, forest accessibility and differences on infrastructure and prices. Residents of large cities (both Osorno and Puerto Montt) compared to rural counterparts were more likely to choose luma-tepú than eucalyptus, but less likely to choose other tree species (less known by the urban population). The probability of consuming luma-tepú was about 13.5 % and 20.1 % higher for households from Puerto Montt and medium cities, respectively, than rural households, while the probability of consuming eucalyptus alone was 32.4 % lower for households in medium cities (they prefer other native species). Residents of medium cities compared to rural counterparts were more likely to choose all three tree species categories as compared to exclusive consumption of eucalyptus.

Our findings reveal the critical role of spatial variation in fuelwood preference along the rural-urban gradient, in response to tree species availability. However, purchased fuelwood (mostly for urban consumption), can have a wider spatial impact on forests as, in this case, fuelwood is not tied to the local forests and can be supplied from other regions, unlike collected fuelwood. This could be moving the pressure of the fuelwood market on some species, forests, and territories, based on preferences of urban consumers.

Our finding also reveals a significant variation of species choice for fuelwood from province to province. For instance, on average, households in Osorno province had about 9.7 % lower and 26.3 % higher probability of consuming luma-tepú and Ulmo-Hualle, respectively, than households in the provinces of Llanquihue and Chiloé, which is related to species availability in the surrounding forests (*Nothofagus* forests in the Osorno province versus evergreen forests in the Llanquihue province).

Determinants of preferred tree species choice

The estimated coefficients and the Marginal Effects of the GLOGIT model were presented in Appendix Table A.4. Our discussion focuses on the marginal effects in Table 5. We conducted a formal test applying the Brant test and likelihood ratio test to detect if the parallel regression assumption of the ordered logit model is violated. The Brant test (see Appendix Table A.5) confirm that the parallel regression assumption is indeed violated. The Brant test shows that the assumption is violated especially for the cost covariate. Accordingly, the generalized ordered logit model is an appropriate approach for fitting our data.

The FVI is the most important factor people consider in what species to use for firewood. FVI is positively associated with the consumption of highly preferred species and negatively with nonpreferred species groups, and is statistically significant ($P < 0.001$) in both cases (see Table 6). Highly preferred tree species are primarily the high-value native species (Ulmo, Luma and Tepú), and Hualle (see Fig. 2), which people demand because of their wood quality.

Similarly, our result indicates wealthy households (high expenditure/income) were more likely to prefer high-value native species. As a result, higher-income families can enjoy higher-standard heating than poorer ones, as temperatures remain more stable inside their houses. Households who have been living in their current house since 2010 were on average about 8 % less likely to consume highly preferred species and 8.4 % more likely to consume non-preferred tree species than those who started living in their home before 1990. This may relate to the fact that modern building structures have higher thermal insulation standards, so energy demand for heating is lower, which allows people to use non-preferred tree species for fuelwood (lower FVI).

Decision maker's schooling was one of the key factors determining whether a household's consumption decision aligned with their preferred tree species. The marginal effect results show households with decision makers who attended high school and above, respectively, were about 8.5 % and 10 % more likely to consume highly preferred tree species than households whose decision makers attended up to high school or up to elementary school, respectively.

Agreement with the statement that “fuelwood consumption causes deforestation” was related to a lower willingness to buy preferred tree species for fuelwood. On average, households who disagreed with the idea that fuelwood production causes deforestation was about 12.3 % more likely to consume highly preferred species than those who agreed. Our finding is consistent with expectations that environmental concerns ought to be associated with pro-environmental decisions. Those that agreed there was a relationship between fuelwood consumption and deforestation would be expected to be less likely to consume preferred tree species (usually high-value species, like Ulmo and Luma) but instead shift to non-preferred species (more abundant in the forests, like *broza*, or Eucalyptus plantations) as a consequent behavior.

Discussion

Tree species preferences for fuelwood

Research about woodfuel consumption has been mostly focused on cooking, especially in low-income countries. However, the situation in cold countries like Chile, Argentina, New Zealand and others, at high latitudes in the northern and southern hemispheres, is different, as fuelwood is mainly driven by heating with cooking as a secondary activity. This creates a different context for the study of fuelwood consumption that is less well-studied.

Given the significant pressure of fuelwood demand on forests, in this paper, we attempted to examine the drivers of tree species preference for fuelwood, and implications on forests in southern Chile. In general, the results of the different econometric models employed were broadly consistent, and conform to what was expected. These results indicate the important role of FVI, household income/expenditure, awareness of the relationship between fuelwood production and deforestation, and

Table 6
Marginal effects results from the generalized ordered logit model for preferred tree species choice by Chilean households.

Explanatory variables	Non preferred species		Less preferred species		Highly preferred species	
	ME[‡]	SE	ME[‡]	SE	ME[‡]	SE
Fuel value index	−0.0105****	0.0012	0.0005	0.0004	0.0100****	0.0011
Expenditure (log)	−0.0333**	0.0164	0.0016	0.0014	0.0317**	0.0157
Size of dwelling area (log)	−0.0126	0.0317	0.0006	0.0015	0.0120	0.0303
Started living (during 1990 to 2010)[a]	0.0239	0.0275	−0.0011	0.0016	−0.0228	0.0263
Started living (since 2010)[a]	0.0843**	0.0396	−0.0040	0.0035	−0.0803**	0.0381
Dec.maker's age	0.0020	0.0018	−0.0001	0.0001	−0.0019	0.0017
Dec.maker's gender	0.0500*	0.0289	−0.0024	0.0021	−0.0476*	0.0279
Dec.maker high school[b]	−0.0887*	0.0454	0.0042	0.0036	0.0845*	0.0440
Dec.maker's above high school[b]	−0.0312	0.0464	−0.0698**	0.0320	0.1010**	0.0442
Household size	0.0067	0.0130	−0.0003	0.0007	−0.0064	0.0124
Quality	−0.0404	0.0387	0.0019	0.0022	0.0385	0.0371
cost	−0.0635*	0.0379	0.0873**	0.0339	−0.0238	0.0353
Accessibility	−0.0551	0.0451	0.0026	0.0028	0.0524	0.0432
Others	−0.1077	0.0753	0.0051	0.0054	0.1025	0.0717
Deforestation in county (neutral)[c]	0.0985	0.0637	−0.0047	0.0040	−0.0938	0.0618
Deforestation in county (disagree)[c]	0.0477	0.0571	−0.0023	0.0028	−0.0455	0.0549
Fuelwood cause deforestation (netural)[d]	−0.1057	0.0695	0.0050	0.0048	0.1007	0.0668
Fuelwood cause deforestation (disagree)[d]	−0.0115	0.0641	−0.1119****	0.0373	0.1234**	0.0564
Province -Osorno[e]	0.0571	0.0594	−0.0027	0.0026	−0.0543	0.0576
Province Palena[e]	0.0924	0.0659	−0.0044	0.0041	−0.0880	0.0636
Large city - Puerto Montt[f]	−0.0148	0.0574	0.0007	0.0031	0.0141	0.0544
Large city - Osorno[f]	−0.4119****	0.0631	0.2017****	0.0357	0.2102****	0.0552
Medium cities[f]	−0.1184*	0.0668	0.0057	0.0057	0.1127*	0.0634
Small cities[f]	−0.0697	0.0549	0.0033	0.0041	0.0663	0.0518

Note: standard errors are cluster robust with place of city.
* $p < 0.10$.
** $p < 0.05$.
**** $p < 0.001$.
‡ The average marginal effects and their *p*-values were obtained by the margins command in Stata.
a Refernce group before 1990.
b Reference group no education or primary school.
c Refernce group neutral about deforestation in your county.
d Reference group neutral about fuelwood cause deforestation.
e Reference group Llanquihue and Chiloé.
f Reference group was rural.

spatial heterogeneity in determining household tree species preference for fuelwood. The FVI and household wealth (expenditure) all had a positive influence on the consumption of the highly preferred tree species, especially in urban areas. The three main preferred species (Ulmo, Luma and Tepú) have key characteristics as a fuel for heating, which go beyond their high FVI. In all these cases, people value the wood's energy intensity, flame duration and the presence of embers, which keep the home warmer through the day, especially at night, and facilitate lighting the woodstove the next morning (Schueftan et al., 2016).

We note that tree species preference itself is based largely on combustible attributes and it is known that local knowledge plays a role in identifying species with better combustion properties (Cardoso et al., 2015). We would then expect that traditional ecological knowledge in particular would play a role in more rural areas in shaping stated tree species preferences but not the revealed/actual tree specie consumption choice or preferred tree species choice (which are the focus this paper) while urban populations (especially in large centres such as Osorno or Port Montt) may be more influenced by other factors. We recognize this is an underlying dimension of this research that may not be well captured by a simple educational variable and calls for further research.

Concerning the FVI, our finding conforms to the findings of a previous study in Brazil that indicated a significant and positive relationship of household fuelwood tree species preference with the FVI (Ramos et al., 2008). The species with good combustion characteristics were preferred in Uganda as well (Agea et al., 2010). Our finding shows that fuelwood consumers tend to choose tree species that provide them with high utility (i.e., high heat value), when their budget allows them to buy these species in the local fuelwood market. This shows the importance of studying both the physical characteristics of the fuel and socioeconomic characteristics of households and decision makers, as we attempted to do for the first time in this study.

Low-quality fuelwood produces less embers, so people have to feed their woodstoves more frequently ("*fuelwood burns like paper*", according to some survey respondents), as most homes are poorly insulated (Schueftan et al., 2016). This results in heat peaks, which can raise indoor temperatures above 30 °C (Reyes et al., 2019), as most of the woodstoves used in Chile do not have effective mechanisms to control the burning rate. So, in the context of homes poorly insulated, heating quality directly depends on timber quality. Related to this, we observed that families living in newer homes have a lower probability of consuming high FVI species than others. As thermal insulation standards in Chile have significantly improved after 2010 (Schueftan et al., 2016; Reyes et al., 2019), newer homes have better thermal insulation. This reduces the total energy demand for heating (kilowatt per year) (Schueftan et al., 2016), and allows people to consume lower quality timbers for fuelwood, saving money (because they are cheaper), and better controlling indoor temperature (avoiding heat peaks). From this perspective, thermal insulation is a good measure not only to reduce atmospheric air pollution but also to protect forests.

Awareness of deforestation, moreover, leads households to buy non-preferred species for fuelwood. This indicates consumers' environmental concern is an important factor driving people's fuelwood preferences, as they are able to link fuelwood consumption of preferred species, like Ulmo, Luma and Tepú, which are being strongly pressured by the fuelwood market, with negative consequences in their local landscape (deforestation). This observation makes them more prone to change their decisions about fuelwood supply, and buy the most abundant tree species for fuelwood, even though these species have a lower FVI, and are not as effective for heating. This small "sacrifice" that people are willing to do is an interesting finding of this research, as it shows that environmental awareness can effectively turn into concrete behaviors, with a positive impact on local ecosystems. This willingness to change behaviors can be consequence of the Firewood Certification System that have been in place in the Los Lagos region since 2006, which has been also mentioned by other authors (Conway, 2012; Vásquez-Lavin et al., 2020; García et al., 2021).

The negative likelihood of consuming high-value native species such as Luma-Tepú as compared to Eucalyptus alone likely stems from budget pressure or low per capita income to afford those expensive species. In the context of a well-established fuelwood market, as is the case of Chile, household income is a powerful driver of forest degradation, as people can get the best tree-species for heating (higher FVIs) independent of forest location and accessibility (supply distance). Lower-income families tend to buy lower quality tree-species for fuelwood, which are more abundant in forests, or even planted tree-species like Eucalyptus, to meet their energy needs. We observed a similar influence on the size of the dwelling area. The likelihood of consuming Luma-Tepú and other species category compared to eucalyptus tend to decrease as the size of the dwelling area increase. This is because more fuelwood is needed to meet residential heating demand as the dwelling size increase (higher expense). Studies have indicated a positive relationship between family size and the amount of fuelwood consumption (Agea et al., 2010), and between the later and income in Brazil (de Arruda et al., 2019).

Our finding regarding the significant role of spatial heterogeneity in tree species preference for fuelwood also conforms to studies in other regions of the world. For instance, in Bangladesh, a study indicated that the pattern of fuelwood consumption varied between regions (Hassan et al., 2013) due to consumers ́constraints in affording commercial fuels, which was not the case in this study as most of the households were fuelwood purchasers (about 75 %). The type of species and their relative abundance in forests within the region is an important factor in determining which species households prefer or consume. We recommend that future studies explicitly incorporate the urban-rural gradients of species abundance/distribution into household fuelwood tree species. In particular, in rural areas, where people collect fuelwood, distance to the forest and tree species abundance are expected to play an important role in which species they collect/consume.

Implications for native forests

Our findings reveal a high preference for high-value native species, mainly Ulmo, Luma and Tepú, in the Los Lagos region of Chile, which could have negative consequences on forest ecosystems. Studies elsewhere also indicated the negative impact of fuelwood extraction on the diversity and population of preferred tree species (Lynser et al., 2020). It causes greater pressure, especially in areas with low availability of forests and high settlement areas, as is the case of Puerto Montt city, the largest urban area in this region (Chettri et al., 2002). By contrast, in Osorno city, the second largest urban centre, people were more likely to choose ulmo-hualle, which are abundant around the city, as is Eucalyptus, instead of other native species. These species grow on much better soils than Tepú and Luma, and have higher yields (Donoso et al., 1993; Uteau and Donoso, 2009).

The impact that fuelwood production exerts on forests and biodiversity conservation varies depending on the fuelwood demand, the area of forests that are available to produce fuelwood and their productivity (which also depends on soil characteristics), and the tree-species ́ ecological characteristics. The high-value native species, Luma, Ulmo and Tepú, are shade tolerant (Luma and Tepú) and intermediate shade-tolerant (Ulmo) trees common in forests at an advanced successional stage (Bannister, 2018). These tree species grow slowly, especially Luma and Tepú, so they need a long time to accumulate biomass before being harvested.

In the case of Tepu, this tree species tends to create monospecific stands named "tepuales", while Ulmo and Luma usually grow in mixed stands. In the case of Tepu, forestry operations usually produce significant impacts, as these trees grow on wetlands, peatlands and fragile soils, and they are intensively harvested. Tepu cannot regenerate after intense forestry operations, which makes its recovery more difficult, so logging can usually end in deforestation or a highly degraded forest (Bannister, 2018). The case of Luma and Ulmo is different, as these are harvested by using selective logging, which results in fewer impacts and allows these species to regrow and regenerate. Other native species, like Canelo (commonly sold as *broza* in the firewood market) and Hualle, the last one highly preferred by fuelwood consumers, are more abundant as they can colonize lands after natural or human disturbances. They grow faster on more productive soils; Hualle in the Osorno province and Canelo southwards.

Eucalyptus, by contrast, is an exotic species that needs just 10 or 15 years of growth to be harvested for fuelwood. Thousands of hectares of Eucalyptus plantations were planted in the Los Lagos region (mainly in the Osorno and Llanquihue provinces). Eucalyptus plantations are harvested like any crop, through simpler and cheaper forestry operations than the ones performed on native forests. This is an important advantage of Eucalyptus plantations as a fuelwood supply source and could reduce pressure on native forests, as long as they do not replace native forests (Clapp, 2001).

Moreover, the misalignment between revealed and stated tree species preferences could be showing supply constraints. This is observed in Puerto Montt, the largest city in the region, which is having difficulties meeting its demand for preferred tree species for fuelwood –mainly Luma, Ulmo and Tepu- in comparison to other cities. This is consistent with studies that show a high level of deforestation and forest degradation in the region around the city (Marín et al., 2011; Echeverria et al., 2012; Reyes, 2021a). One of the most critical environmental characteristics of this area is the presence of waterlogged volcanic ash soils, locally called "Ñadi" or "seasonal swamp" (Zúñiga et al., 2019). This determines a low productivity of forests and tree plantations, and longer biomass-recovering periods (Gerding et al., 2014). In fact, most of Tepu consumed in Puerto Montt is coming from Chiloe Island, as Tepu forests in other supply zones, closer to the city, have disappeared (Echeverria et al., 2012).

Based on this, policies oriented to speed up the energy transition in Puerto Montt by encouraging the use of more efficient wood pellets and electricity (Chile's electricity mix is a little over 50 % renewable and would mean less combustion within households) for household heating should be a priority. This transition could stabilize the volume of fuelwood consumed in this city, decoupling fuelwood consumption and the city's demographic growth. A trend in this direction has been already observed by SICAM (2019) and Reyes (2021b).

Conclusion

We applied econometric models to investigate the preference for fuelwood tree species in Chile, a high latitude country, where fuelwood consumption is mainly driven by heating rather than cooking. Our study focuses on underlying factors determining household fuelwood choices, by comparing revealed versus stated tree-species preferences. Our findings are consistent and align with theory and prior empirical findings.

Our findings indicate that many HHs consume high-value native species, which may cause forest degradation but not necessarily deforestation, as most of them are harvested using selective logging. The case of Tepu is different, as this tree-species is being harvested by using more intense extractive methods, and it is located on fragile and low productivity soils. Consumption of exotic species (e.g. Eucalyptus) may create incentives for plantations, which would reduce the pressure on other native species in the future as they create a new and highly productive biomass source. Yet, this may also result in the replacement of natural forest, if the expansion of these plantations is unregulated.

These findings show that tree-species preferences for fuelwood are a fundamental aspect to be addressed when the relationship between fuelwood consumption and deforestation/forest degradation is analyzed. Impacts on forests can widely vary, depending on tree species ecological characteristics, and differences in harvesting methods, and as also their chances to regenerate after forestry operations. Our findings reveal the critical role of spatial variation in fuelwood preference along the rural-urban gradient, in response to tree species availability. However, purchased fuelwood (mostly for urban consumption) can have a wider spatial impact on forests as, in this case, fuelwood is not tied to the local forests and can be supplied from other regions, unlike collected fuelwood. This could be moving the pressure of the fuelwood market on some species, forests, and territories, based on preferences of urban consumers. The finding of this study points to improving regulations that aim to promote more sustainable consumption decisions, better regulate local fuelwood markets, and strengthen the control and protection on some kind of forests and regions.

This study allows us to better understand the relationship between household fuelwood preferences, and their environmental implications on forests, in the context of a middle-income country with both similarities and differences to other developing and developed countries where fuelwood is commonly used. The South of Chile was an ideal choice for such analysis, as fuelwood is provided by both a mix of native forests and Eucalyptus plantations and commercial fuelwood can be transported over significant distances. The latter allows distinguishing between stated and revealed preferences based on a range of available species that are not as tied to the local forests as with self-collection, which differs from other developing countries, where fuelwood is locally collected. At the same time, most fuelwood comes from illegal logging, which adversely affects forest sustainability, and it is an important difference with high income countries where fuelwood consumption is a significant part of the energy matrix (e.g. Sweden or Finland). In between both extremes, the Chilean case is the missing piece to adequately understand how fuelwood consumption relates to forest conservation.

Finally, we note that, despite the COVID-19 lockdowns, the fuelwood supply chain remained working in the Los Lagos region, as fuelwood was considered a basic supply by the Chilean Government. Fuelwood production and transport never stopped during 2020, which allowed it to adequately supply the higher urban demand for energy for heating that resulted from a more intense use of homes (remote work). This shows the higher resiliency of the fuelwood supply chain in comparison with other fuels, which is grounded on strong local rural-urban connections that relate energy consumers and producers. The pandemic showed the importance of having local energy suppliers, especially when most other fuels, in the case of Chile, are imported or depend on imported inputs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A.1
Scientific name of tree species preferred for firewood (stated preference).

S/N	Species name	Scientific name of species
1	Álamo	Populus sp.
2	Aromo	Acacia sp.
3	Arrayán	Luma apiculate
4	arrayán-luma	
5	Broza	Mix of native woods
6	Canelo	*Drimys winteri*
7	canelo - tepa	*Drimys winteri* - Laureliopsis philippiana
8	Cerezo	Prunus sp.
9	Ciprés	Cupressus sp.
10	Ciruelillo	*Embothrium coccineum*
11	Coigue	*Nothofagus dombeyi*
12	coigue-mañío	
13	Eucalipto	Eucalyptus sp
14	eucalipto - pino	
15	Frutales	Mix of fruit trees
16	Hualle	*Nothofagus obliqua*
17	hualle - eucalipto	
18	Laurel	Laurelia sempervirens
19	Lenga	Nothofagus pumilio
20	Lingue	Persea lingue
21	Luma	Amomyrtus luma
22	luma-tineo	
23	luma-ulmo	
24	luma-ulmo-tepú	
25	Maitén	*Maytenus boaria*
26	Mañío	Podocarpus sp.
27	mañío-coigue	
28	Manzano	Malus sp.
29	Ñirre	Nothofagus antarctica
30	Olivillo	Aextoxicon punctatum
31	olivillo - luma	

(*continued on next page*)

Table A.1 (*continued*)

S/N	Species name	Scientific name of species
32	palo santo	Dasyphillum diacanthoides
33	Patagua	Crinodendron patagua
34	Pino	*Pinus radiata*
35	Pitra	Myrceugenia exsucca
36	Radal	Lomatia hirsute
37	Temu	Blepharocalyx cruckshanksii
38	temu - luma	
39	tepú - hualle	
40	Tepú	Tepualia stipularis
41	tepú-luma	
42	tepú-ulmo	
43	Tiaca	Caldcluvia paniculate
44	Tineo	Weinmannia trichosperma
45	tineo-luma	
46	Ulmo	Eycryphia cordifolia
47	ulmo-luma	
48	ulmo-luma-tepú	

Note: the shaded cells show breaded species.

Table A.2
Generalized ordered logit estimation results for the determinants of preferred species choice (dependent variable rank of revealed vs. stated species preference; perception variables excluded).

Explanatory variables	Y > 1			Y > 2		
	Coeff.	Std. Err.	Odd ratio	Coeff.	Std. Err.	Odd ratio
Fuel value index	0.0582****	0.0085	1.06	0.0582****	0.0085	1.06
Expenditure (log)	0.1844**	0.0879	1.20	0.1844**	0.0879	1.20
Size of dwelling area (log)	0.0697	0.1754	1.07	0.0697	0.1754	1.07
Started living (during 1990 to 2010)[a]	−0.1326	0.1523	0.88	−0.1326	0.1523	0.88
Started living (since 2010)[a]	−0.4677**	0.2157	0.63	−0.4677**	0.2157	0.63
Dec.maker's age	−0.0109	0.0098	0.99	−0.0109	0.0098	0.99
Dec.maker's gender	−0.2773*	0.1649	0.76	−0.2773*	0.1649	0.76
Dec.maker high school[b]	0.4920*	0.2572	1.64	0.4920*	0.2572	1.64
Dec.maker's above high school[b]	0.1732	0.2595	1.19	0.5883**	0.2515	1.80
Household size	−0.0371	0.0714	0.96	−0.0371	0.0714	0.96
Quality	0.2241	0.2167	1.25	0.2241	0.2167	1.25
cost	0.352	0.2153	1.42	−0.1385	0.2080	0.87
Accessibility	0.3054	0.2498	1.36	0.3054	0.2498	1.36
Others	0.597	0.4191	1.82	0.597	0.4191	1.82
Province –Osorno[c]	−0.3165	0.3329	0.73	−0.3165	0.3329	0.73
Province Palena[c]	−0.5125	0.3705	0.60	−0.5125	0.3705	0.60
Large city - Puerto Montt[d]	0.0819	0.3174	1.09	0.0819	0.3174	1.09
Large city - Osorno[d]	2.2844****	0.3362	9.82	1.2243****	0.3419	3.40
Medium cities[d]	0.6564*	0.3820	1.93	0.6564*	0.3820	1.93
Small cities[d]	0.3863	0.3047	1.47	0.3863	0.3047	1.47
Constant	−3.8562**	1.5558	0.02	−5.2455****	1.4824	0.01
Alternative parameterization: Gammas are deviations from proportionality						
	Coeff.	SE	z	P > |z|	Odd ratio	
Beta						
Fuel value index	0.0575	0.00828	6.95	0	1.06	
Expenditure (log)	0.1822	0.08730	2.09	0.037	1.20	
Size of dwelling area (log)	0.0436	0.17950	0.24	0.808	1.04	
Started living (during 1990 to 2010)[a]	−0.1436	0.15648	−0.92	0.359	0.87	
Started living (since 2010)[a]	−0.4421	0.22746	−1.94	0.052	0.64	
Dec.maker's age	−0.0102	0.00979	−1.05	0.295	0.99	
Dec.maker's gender	−0.2803	0.15391	−1.82	0.069	0.76	
Dec.maker high school[b]	0.4675	0.25539	1.83	0.067	1.60	
Dec.maker's above high school[b]	0.1495	0.26278	0.57	0.569	1.16	
Household size	−0.0449	0.06535	−0.69	0.492	0.96	
Quality	0.2424	0.21766	1.11	0.266	1.27	
cost	0.3505	0.19279	1.82	0.069	1.42	
Accessibility	0.2973	0.23893	1.24	0.213	1.35	
Others	0.6148	0.42879	1.43	0.152	1.85	
Province -Osorno[c]	−0.3495	0.33186	−1.05	0.292	0.71	
Province Palena[c]	−0.5749	0.36783	−1.56	0.118	0.56	
Large city - Puerto Montt[d]	0.0686	0.30122	0.23	0.82	1.07	
Large city - Osorno[d]	2.2424	0.33770	6.64	0	9.42	
Medium cities[d]	0.6235	0.36584	1.7	0.088	1.87	
Small cities[d]	0.3911	0.30582	1.28	0.201	1.48	
Gamma_2						
Dec.maker high school	0.4313	0.1914	2.25	0.024	1.54	
Cost	−0.4710	0.1809	−2.6	0.009	0.62	
Large city - Osorno[d]	−1.0342	0.1359	−7.61	0	0.36	

(*continued on next page*)

Table A.2 (*continued*)

Explanatory variables	Y > 1			Y > 2		
	Coeff.	Std. Err.	Odd ratio	Coeff.	Std. Err.	Odd ratio
Alpha						
_cons_1	−3.7084	1.5886	−2.33	0.02		
_cons_2	−5.0055	1.5544	−3.22	0.001		
LR chi2(20)	2547.92 ($P < 0.000$)					
Log pseudolikelihood	*−487.61*					
Pseudo R2	0.16					
N	534					

Note standard errors are cluster robust with place of city.
[*] $p < 0.10$.
[**] $p < 0.05$.
[****] $p < 0.001$.
[a] Refernce group before 1990.
[b] Reference group no education or primary school.
[c] Refernce group Llanquihue and Chiloé.
[d] Reference group was rural.

Table A.3
Multinomial logit model results of the determinants of main tree species choice for fuelwood by Chilean households.

Explanatory variables	Species categories[‡]		
	Luma-Tepú	Ulmo-Hualle	others
Fuel Value Index	0.0785****	0.0358***	0.0424****
	(0.0138)	(0.0138)	(0.0129)
Expenditure (log)	0.1857	0.0712	0.2691
	(0.3186)	(0.2701)	(0.2403)
Size of dwelling area (log)	−0.6182*	−0.2378	−0.7243***
	(0.3521)	(0.2968)	(0.2673)
Started living -during 1990 to 2010[a]	−0.0546	−0.1133	0.0394
	(0.5222)	(0.4222)	(0.3957)
Started living since 2010[a]	−0.0816	−0.1896	0.1897
	(0.5608)	(0.4811)	(0.4356)
Decion maker's age	−0.0015	0.0324**	0.0130
	(0.0163)	(0.0143)	(0.0124)
Decision maker's gender (male)	−0.2000	0.1324	0.3178
	(0.3702)	(0.3154)	(0.2820)
Decision maker's education high school[b]	0.0350	1.3892***	−0.0809
	(0.4768)	(0.4277)	(0.3586)
Decision maker's education above high school[b]	−0.4257	1.1098**	−0.4546
	(0.5413)	(0.4737)	(0.4084)
Family size	−0.3096**	−0.0865	−0.1019
	(0.1333)	(0.1109)	(0.0941)
Quality	−0.2003	0.0563	−0.2697
	(0.4432)	(0.3993)	(0.3483)
Cost	−0.5752	−0.2284	−0.5937*
	(0.4572)	(0.4012)	(0.3461)
Availability	0.3753	0.1544	−0.1043
	(0.4968)	(0.4528)	(0.3770)
Other	−0.7911	0.2889	0.0708
	(0.9683)	(0.6768)	(0.5720)
Deforestation in county (neutral)[c]	−0.9695	0.4216	0.0468
	(0.8033)	(0.5948)	(0.5494)
Deforestation in county (disagree)[c]	0.6062	0.0625	0.4434
	(0.7938)	(0.6427)	(0.5973)
Fuelwood cause deforestation (Neutral)[d]	−0.1723	0.7693	0.6612
	(0.8391)	(0.6549)	(0.6160)
Fuelwood cause deforestation (disagree)[d]	0.9827	0.0925	−0.1127
	(0.7549)	(0.6067)	(0.5600)
Province -Osorno[e]	1.0384	−1.8283	0.4362
	(0.7358)	(1.1539)	(0.5705)
Province -Palena[e]	0.7105	0.3789	0.7340
	(0.8114)	(0.7380)	(0.6085)
Large city -Osorno[f]	0.6436	−0.4201	−0.9070**
	(0.6133)	(0.5474)	(0.4411)
Large city - Puerto Montt[f]	−17.1236	1.4105	−3.2019****
	(845.1297)	(1.1749)	(0.6576)
Medium cities[f]	4.5027****	2.3425**	2.8182***
	(1.1537)	(1.1563)	(1.0829)
Small cities[f]	0.6522	0.4770	0.1469
	(0.6097)	(0.5645)	(0.4511)
_cons	−1.8521	−3.4444	−0.4857
	(4.4200)	(3.8198)	(3.3135)

(*continued on next page*)

Table A.3 (*continued*)

Explanatory variables	Species categories[‡]		
	Luma-Tepú	Ulmo-Hualle	others
N	84	93	273
LR chi2(69)	378.30 ($P < 0.0000$)		
Log likelihood	−509.10		
Pseudo R2	0.27		
Overall N	555		

Note: Base category Eucalipto only.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.
‡ The model includes all households who consumed fuelwood including those who did not state their preferred species (n = 21, 4 %).
[a] Refernce group before 1990.
[b] Reference group no education or primary school.
[c] Refernce group neutral about deforestation in your county.
[d] Reference group neutral about fuelwood cause deforestation.
[e] Reference group Llanquihue and Chiloé.
[f] Reference group was rural.

Table A.4
Generalized ordered logit estimation results for the determinants of preferred tree species choice.

Explanatory variables***	Y > 1			Y > 2		
	Coeff.	Std. Err.	Odd ratio	Coeff.	Std. Err.	Odd ratio
Fuel value index	0.0582****	0.0085	1.06	0.0582****	0.0085	1.06
Expenditure (log)	0.1844**	0.0879	1.20	0.1844**	0.0879	1.20
Size of dwelling area (log)	0.0697	0.1754	1.07	0.0697	0.1754	1.07
Started living (during 1990 to 2010)[a]	−0.1326	0.1523	0.88	−0.1326	0.1523	0.88
Started living (since 2010)[a]	−0.4677**	0.2157	0.63	−0.4677**	0.2157	0.63
Dec.maker's age	−0.0109	0.0098	0.99	−0.0109	0.0098	0.99
Dec.maker's gender	−0.2773*	0.1649	0.76	−0.2773*	0.1649	0.76
Dec.maker high school[b]	0.4920*	0.2572	1.64	0.4920*	0.2572	1.64
Dec.maker's above high school[b]	0.1732	0.2595	1.19	0.5883**	0.2515	1.80
Household size	−0.0371	0.0714	0.96	−0.0371	0.0714	0.96
Quality	0.2241	0.2167	1.25	0.2241	0.2167	1.25
cost	0.352	0.2153	1.42	−0.1385	0.2080	0.87
Accessibility	0.3054	0.2498	1.36	0.3054	0.2498	1.36
Others	0.597	0.4191	1.82	0.597	0.4191	1.82
Deforestation in county (neutral)[c]	−0.546	0.3638	0.58	−0.546	0.3638	0.58
Deforestation in county (disagree)[c]	−0.2647	0.3176	0.77	−0.2647	0.3176	0.77
Fuelwood cause deforestation (netural)[d]	0.5861	0.3871	1.80	0.5861	0.3871	1.80
Fuelwood cause deforestation (disagree)[d]	0.0637	0.3562	1.07	0.7185**	0.3224	2.05
Province -Osorno[e]	−0.3165	0.3329	0.73	−0.3165	0.3329	0.73
Province Palena[e]	−0.5125	0.3705	0.60	−0.5125	0.3705	0.60
Large city - Puerto Montt[f]	0.0819	0.3174	1.09	0.0819	0.3174	1.09
Large city - Osorno [f]	2.2844****	0.3362	9.82	1.2243****	0.3419	3.40
Medium cities[f]	0.6564*	0.3820	1.93	0.6564*	0.3820	1.93
Small cities[f]	0.3863	0.3047	1.47	0.3863	0.3047	1.47
Constant	−3.8562**	1.5558	0.02	−5.2455****	1.4824	0.01

Alternative parameterization: Gammas are deviations from proportionality	Coeff.	SE	Z	P > |z|	Odd ratio
Beta					
Fuel value index	0.0582	0.0085	6.85	0	1.060
Expenditure (log)	0.1844	0.0879	2.1	0.036	1.203
Size of dwelling area (log)	0.0697	0.1754	0.4	0.691	1.072
Started living (during 1990 to 2010)[a]	−0.1326	0.1523	−0.87	0.384	0.876
Started living (since 2010)[a]	−0.4677	0.2157	−2.17	0.03	0.626
Dec.maker's age	−0.0109	0.0098	−1.11	0.265	0.989
Dec.maker's gender	−0.2773	0.1649	−1.68	0.093	0.758
Dec.maker high school[b]	0.4920	0.2572	1.91	0.056	1.636
Dec.maker's above high school[b]	0.1732	0.2595	0.67	0.505	1.189
Household size	−0.0371	0.0714	−0.52	0.603	0.964
Quality	0.2241	0.2167	1.03	0.301	1.251
cost	0.3520	0.2153	1.64	0.102	1.422
Accessibility	0.3054	0.2498	1.22	0.221	1.357
Others	0.5970	0.4191	1.42	0.154	1.817
Deforestation in county (neutral)[c]	−0.5460	0.3638	−1.5	0.133	0.579
Deforestation in county (disagree)[c]	−0.2647	0.3176	−0.83	0.404	0.767
Fuelwood cause deforestation (netural)[d]	0.5861	0.3871	1.51	0.13	1.797

(*continued on next page*)

Table A.4 (*continued*)

Alternative parameterization: Gammas are deviations from proportionality	Coeff.	SE	Z	P > |z|	Odd ratio
Fuelwood cause deforestation (disagree)[d]	0.0637	0.3562	0.18	0.858	1.066
Province -Osorno[e]	−0.3165	0.3329	−0.95	0.342	0.729
Province Palena[e]	−0.5125	0.3705	−1.38	0.167	0.599
Large city - Puerto Montt[f]	0.0819	0.3174	0.26	0.796	1.085
Large city - Osorno[f]	2.2844	0.3362	6.8	0	9.819
Medium cities[f]	0.6564	0.3820	1.72	0.086	1.928
Small cities[f]	0.3863	0.3047	1.27	0.205	1.472
Gamma_2					
Dec.maker high school	0.4151	0.1716	2.42	0.016	1.515
Cost[b]	−0.4906	0.2001	−2.45	0.014	0.612
Fuelwood cause deforestation (disagree)[d]	0.6549	0.2109	3.1	0.002	1.925
Large city - Osorno[f]	−1.0600	0.1468	−7.22	0	0.346
Alpha					
_cons_1	−3.8562	1.5558	−2.48	0.013	
_cons_2	−5.2455	1.4824	−3.54	0	
LR chi2(23)	15,420.98 (P < 0.000)				
Log pseudolikelihood	*−482.69*				
Pseudo R2	0.17				
N	534				

Note: standard errors are cluster robust with place of city.

* $p < 0.10$.

** $p < 0.05$.

*** $p < 0.01$.

**** $p < 0.001$.

[a] Refernce group before 1990.

[b] Reference group no education or primary school.

[c] Refernce group neutral about deforestation in your county.

[d] Reference group neutral about fuelwood cause deforestation.

[e] Reference group Llanquihue and Chiloé.

[f] Reference group was rural.

Table A.5
Brant test of parallel regression assumption.

	chi2	p > chi2	df
All	42.81	0.01	24
Fuel value index	0.26	0.607	1
Expenditure (log)	0.98	0.322	1
Size of dwelling area (log)	0.42	0.519	1
Started living (during 1990 to 2010)[a]	0.55	0.457	1
Started living (since 2010))[a]	3.48	0.062	1
Dec.maker's age	0.5	0.479	1
Dec.maker's gender	0.88	0.35	1
Dec.maker high school)[b]	0.18	0.668	1
Dec.maker's above high school[b]	2.36	0.125	1
Household size	0.33	0.568	1
Quality	0.99	0.319	1
cost	6.78	0.009	1
Accessibility	1.53	0.216	1
Others	1.81	0.179	1
Deforestation in county (neutral)[c]	0.09	0.77	1
Deforestation in county (disagree)[c]	0.34	0.559	1
Fuelwood cause deforestation (netural)[d]	0.11	0.741	1
Fuelwood cause deforestation (disagree)[d]	5.67	0.017	1
Province -Osorno[e]	0	0.978	1
Province Palena[e]	0.16	0.692	1
Large city - Puerto Montt [f]	0.28	0.598	1
Large city - Osorno[f]	3.28	0.07	1
Medium cities[f]	0.02	0.89	1
Small cities[f]	0.62	0.429	1

[a] Refernce group before 1990.

[b] Reference group no education or primary school.

[c] Refernce group neutral about deforestation in your county.

[d] Reference group neutral about fuelwood cause deforestation.

[e] Reference group Llanquihue and Chiloé.

[f] Reference group was rural.

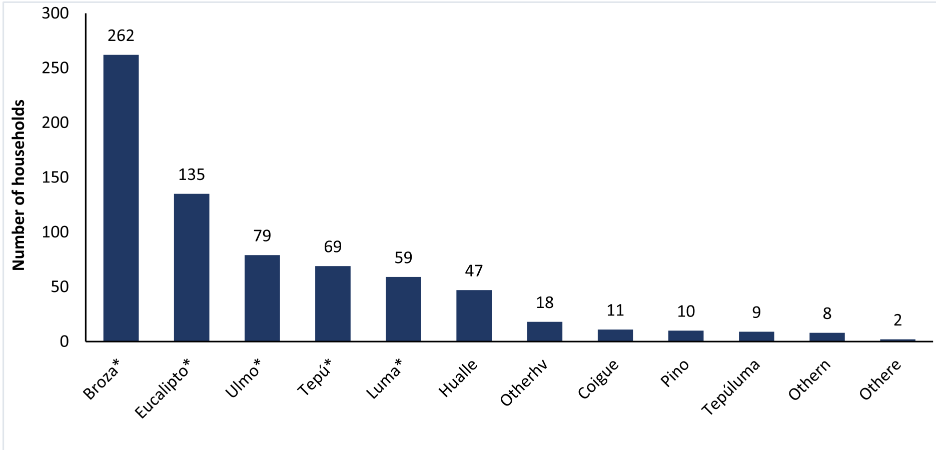

Fig. A.1. Distribution of households by stated preferences rank.
Note: othere denotes other exotic species, otherhv represents other high-value species, and othern denotes other native species
* Stands for most frequently consumed species.

References

Ábalos, M. (1997). Estimación del consumo de leña en las regiones V. In *IX y X. Tesis para optar al título de Ingeniero Forestal. Universidad de Chile. Santiago, Chile* (p. 115).

Agarwal, B. (2021). *Use, degradation, and conservation*. Econ: Routledge Handb. Fem.

Agea, J. G., Kirangwa, D., Waiswa, D., & Okia, C. A. (2010). *Household firewood consumption and its dynamics in Kalisizo Sub-County, Central Uganda*.

Aidoo, E. N., & Ackaah, W. (2019). A generalized ordered logit analysis of risk factors associated with driver injury severity. *Journal of Public Health*, 1–7.

Arabatzis, G., & Malesios, C. (2013). Pro-environmental attitudes of users and non-users of fuelwood in a rural area of Greece. *Renewable and Sustainable Energy Reviews, 22*, 621–630. https://doi.org/10.1016/j.rser.2013.02.026

Arnold, J. M., Köhlin, G., & Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: changing perspectives. *World Development, 34*, 596–611.

Arnold, M., Köhlin, G., Persson, R., & Shepherd, G. (2003). *Fuelwood Revisited: What has changed in the last decade?*.

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change, 5*, 266–272.

Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., & Sarkar, R. (2010). The environmental impact of poverty: evidence from firewood collection in rural Nepal. *Econ. Dev. Cult. Change, 59*, 23–61.

Bannister, Jan (2018). *Tepuales. Tesoro de Chiloé y la Patagonia Insular* (p. 74). Chile: Instituto Forestal. https://doi.org/10.52904/20.500.12220/27284

Boso, et al. (2021). Who buys certified firewood? Individual determinants of clean fuel adoption for promoting the sustainable energy transition in southern Chile. *Energy, Sustainability and Society, 2021*(11:29).

Cardoso, M. B., Ladio, A. H., Dutrus, S. M., & Lozada, M. (2015). Preference and calorific value of fuelwood species in rural populations in northwestern Patagonia. *Biomass and Bioenergy, 81*, 514–520.

Chettri, N., & Sharma, E. (2007). Firewood value assessment: a comparison on local preference and wood constituent properties of species from a trekking corridor, West Sikkim, India. *Curr. Sci.*, 1744–1747.

Chettri, N., Sharma, E., Deb, D. C., & Sundriyal, R. C. (2002). Impact of firewood extraction on tree structure, regeneration and woody biomass productivity in a trekking corridor of the Sikkim Himalaya. *Mountain Research and Development, 22*, 150–158.

Clapp, R. A. (2001). Tree farming and forest conservation in Chile: Do replacement forests leave any originals behind? *Society and Natural Resources, 14*, 341–356. https://doi.org/10.1080/08941920119176

CONAF (Corporación Nacional Forestal). (2017). *Superficies de uso de suelo regional (actualizado a agosto 2017). Versión digital*.

Conway, F. J. (2012). Certification and the State: Market-driven governance and regulation in a Chilean Firewood Program. *The Journal of Environment & Development, 21*(4), 438–461. https://doi.org/10.1177/1070496512449336

Cooke, P., Köhlin, G., & Hyde, W. F. (2008). Fuelwood, forests and community management–evidence from household studies. *Environment and Development Economics, 13*, 103–135.

Cuvilas, C., Lhate, I., Jirjis, R., & Terziev, N. (2014). The characterization of wood species from Mozambique as a fuel. *Energy Sources Part Recovery Util. Environ. Eff., 36*, 851–857.

de Arruda, H. L. S., dos Santos, J. F. O., Albuquerque, U. P., & Ramos, M. A. (2019). Influence of socioeconomic factors on the knowledge and consumption of firewood in the Atlantic forest of Northeast Brazil. *Economic Botany, 73*, 1–12.

Donoso, P, Donoso, C., & Sandoval, V. (1993). Proposición de zonas de crecimiento de renovales de roble (Nothofagus obliqua) y raulí (Nothofagus alpina) en su rango de distribución natural. *Bosque, 14*(2), 37–55. https://doi.org/10.4206/bosque.1993.v14n2-06

Echeverría, C., Newton, A., Nahuelhual, L., Coomes, D., & Rey-Benayas, J. M. (2012). How landscapes change: Integration of spatial patterns and human processes in temperate landscapes of southern Chile. *Applied Geography, 32*(2), 822–831. https://doi.org/10.1016/j.apgeog.2011.08.014

Egeru, A. S. (2014). Rural households' fuelwood demand determinants in dryland areas of Eastern Uganda. *Energy Sources Part B Econ. Planning and Policy, 9*, 39–45.

Eluru, N. (2013). Evaluating alternate discrete choice frameworks for modeling ordinal discrete variables. *Accident; Analysis and Prevention, 55*, 1–11.

Food and Agriculture Organization (FAO). (2019). *Forest Products Annual Market Review 2017-2018*.

García, L. Y., Cerda, A. A., Lagos, R., Muñoz, P., & Muñoz, M. (2021). Society's willingness to pay for certified dry firewood energy in Chile. *Frontiers in Energy Research, 9*, 676654. https://doi.org/10.3389/fenrg.2021.676654

Gerding, V., Thiers, O., Schlatter, J., & Sanzana, J. (2014). Suelos ñadi para una producción forestal sostenible: principales problemas, causas y propuestas de solución. *Bosque Nativo, 53*, 36–43.

GORE Los Lagos (Gobierno Regional de Los Lagos). (2021). *Información de la región*. Available at https://www.goreloslagos.cl/region_lagos/antecedentes_region.html.

Greene, William H. (2012). *Econometric Analysis* (Seventh ed., pp. 803–806). Boston: Pearson Education.

Guta, D. D. (2014). Effect of fuelwood scarcity and socio-economic factors on household bio-based energy use and energy substitution in rural Ethiopia. *Energy Policy, 75*, 217–227.

Hassan, M. K., Halder, P., Pelkonen, P., & Pappinen, A. (2013). Rural households' preferences and attitudes towards biomass fuels-results from a comprehensive field survey in Bangladesh. *Energy Sustain. Soc., 3*, 1–14.

INE (Instituto Nacional de Estadísticas). (2017). *Censo de población y vivienda 2017*. Available at https://www.ine.cl/estadisticas/sociales/censos-de-poblacion-y-vivienda/poblacion-y-vivienda.

Jaime, et al. (2020). Fuel choices and fuelwood use for residential heating and cooking in urban areas of central-southern Chile: the role of prices, income, and the availability of energy sources and technology. *Resource and Energy Economics, 60*(2020), Article 101125.

Johnston, C., McDonald, J., & Quist, K. (2020). A generalized ordered Probit model. *Commun. Stat.-Theory Methods, 49*, 1712–1729.

Jumbe, C. B., & Angelsen, A. (2011). Modeling choice of fuelwood source among rural households in Malawi: a multinomial probit analysis. *Energy Economics, 33*, 732–738.

Kaplan, S., & Prato, C. G. (2012). Risk factors associated with bus accident severity in the United States: a generalized ordered logit model. *Journal of Safety Research, 43*, 171–180.

Kisangau, P. D., Kimiti, J. M., Mburu, M. W., & Snelder, D. J. (2021). Factors influencing use of multipurpose trees and shrubs in arid and semiarid lands of Kenya. *Rangeland Ecology & Management, 74*, 125–134.

Laurance, W. F., Sayer, J., & Cassman, K. G. (2014). Agricultural expansion and its impacts on tropical nature. *Trends in Ecology & Evolution, 29*, 107–116.

Lee, S. M., Kim, Y.-S., Jaung, W., Latifah, S., Afifi, M., & Fisher, L. A. (2015). Forests, fuelwood and livelihoods—energy transition patterns in eastern Indonesia. *Energy Policy, 85*, 61–70.

Lobos, M. (2005). *Poder calorífico de las especies utilizadas como leña*. Comisión Nacional del Medio Ambiente región de La Araucanía: Recopilación no publicada.

Lynser, M. B., Makdoh, K., & Nongbri, B. (2020). Firewood consumption and extraction from community forests in East Khasi Hills District, Meghalaya: Its impact on woody species diversity and population structure. *Tropical Plant Research, 7*(3), 669–677. https://doi.org/10.22271/tpr.2020.v7.i3.084

Malakar, Y., & Day, R. (2020). Differences in firewood users' and LPG users' perceived relationships between cooking fuels and women's multidimensional well-being in rural India. *Nature Energy, 5*, 1022–1031. https://doi.org/10.1038/s41560-020-00722-4
Marín, S., Nahuelhual, L., Echeverría, C., & Grante, W. (2011). Projecting landscape changes in southern Chile: Simulation of human and natural processes driving land transformation. *Ecological Modelling, 222*(15), 2841–2855. https://doi.org/10.1016/j.ecolmodel.2011.04.026
Marquez-Reynoso, M. I., Ramírez-Marcial, N., Cortina-Villar, S., & Ochoa-Gaona, S. (2017). Purpose, preferences and fuel value index of trees used for firewood in El Ocote Biosphere Reserve, Chiapas, Mexico. *Biomass and Bioenergy, 100*, 1–9.
McFadden, D. (1974). Conditional Logit Analysis of Qualitative Choice Behavior. *Frontiers in Econometrics*, 105–142.
Michalaki, P., Quddus, M. A., Pitfield, D., & Huetson, A. (2015). Exploring the factors affecting motorway accident severity in England using the generalised ordered logistic regression model. *Journal of Safety Research, 55*, 89–97.
Ministerio de Energia. (2018). *Anuario estadístico de energía 2018*. Available at https://www.cne.cl/wp-content/uploads/2019/04/Anuario-CNE-2018.pdf.
Mislimshoeva, B., Hable, R., Fezakov, M., Samimi, C., Abdulnazarov, A., & Koellner, T. (2014). Factors influencing households' firewood consumption in the Western Pamirs, Tajikistan. *Mt. Res. Dev., 34*, 147–156.
Ojelel, S., Otiti, T., & Mugisha, S. (2015). Fuel value indices of selected woodfuel species used in Masindi and Nebbi districts of Uganda. *Energy Sustain. Soc., 5*, 1–6.
Palmieri, N., Suardi, A., Latterini, F., & Pari, L. (2020). The eucalyptus firewood: Understanding consumers' behaviour and motivations. *Agriculture, 10*, 512.
Peterson, B., & Harrell, F. E., Jr. (1990). Partial proportional odds models for ordinal response variables. *J. R. Stat. Soc. Ser. C Appl. Stat., 39*, 205–217.
Ramos, M. A., de Medeiros, P. M., de Almeida, A. L. S., Feliciano, A. L. P., & de Albuquerque, U. P. (2008). Can wood quality justify local preferences for firewood in an area of caatinga (dryland) vegetation? *Biomass and Bioenergy, 32*, 503–509.
Reyes, R. (2021a). *Promotores socioeconómicos de la pérdida y degradación del bosque nativo en Chile - Informe técnico. Santiago de Chile, FAO y MINAGRI*. https://doi.org/10.4060/cb0839es
Reyes. (2021b). Consumo de leña y otros biocombustibles sólidos en la región de Los Lagos. Informe final preparado para el Ministerio de Energía. *Instituto Forestal, 71*.
Reyes, R., Nelson, H., Navarro, F., & Retes, C. (2015). The firewood dilemma: Human health in a broader context of well-being in Chile. *Energy for Sustainable Development, 28*, 75–87. https://doi.org/10.1016/j.esd.2015.07.005
Reyes, R., Nelson, H., & Zerriffi, H. (2018). Firewood: Cause or consequence? Underlying drivers of firewood production in the South of Chile. *Energy for Sustainable Development, 42*, 97–108.
Sahoo, U. K., Lalremruata, J., & Lalramnghinglova, H. (2014). Assessment of fuelwood based on community preference and wood constituent properties of tree species in Mizoram, north-east India. *For. Trees Livelihoods, 23*, 280–288.
San, et al. (2012). Fuelwood consumption patterns in Chumriey Mountain, Kampong Chhnang Province, Cambodia. *Energy, 44*, 335–346.
Sassen, M., et al. (2015). Fuelwood collection and its impacts on a protected tropical mountain forest in Uganda. *Forest Ecology and Management, 354*, 56–67.
Schueftan, A., & González, A. (2013). Reduction of firewood consumption by households in south-central Chile associated with energy efficiency programs. *Energy Policy, 63*, 823–832.
Schueftan, A., Sommerhoff, J., & González, A. D. (2016). Firewood demand and energy policy in south-central Chile. *Energy for Sustainable Development, 33*, 26–35. https://doi.org/10.1016/j.esd.2016.04.004
Sedai, P., Kalita, D., & Deka, D. (2016). Assessment of the fuel wood of India: a case study based on fuel characteristics of some indigenous species of Arunachal Pradesh. *Energy Sources Part Recovery Util. Environ. Eff., 38*, 891–897.
Semenya, K., & Machete, F. (2019). Factors that influence firewood use among electrified Bapedi households of Senwabarwana villages, South Africa. *African Journal of Science, Technology, Innovation and Development, 11*, 719–729.
SICAM, 2019. Encuesta de caracterización residencial en relación al consumo de leña y sus artefactos de combustión, comunas de Puerto Montt y Puerto Varas, año 2019. Informe de resultados. estudio encargado por el Ministerio de Medio Ambiente, Chile. 84 p.
Singh, D., Aung, T., & Zerriffi, H. (2018). Resource Collection Polygons: a spatial analysis of woodfuel collection patterns. *Energy for Sustainable Development, 45*, 150–158.
Tabuti, J. R. S., Dhillion, S. S., & Lye, K. A. (2003). Firewood use in Bulamogi County, Uganda: species selection, harvesting and consumption patterns. *Biomass and Bioenergy, 25*(6), 581–596.
Teixeira, S., Sanches-Pereira, A., Tudeschini, L., & Goldemberg, J. (2018). The energy transition history of fuelwood replacement for liquefied petroleum gas in Brazilian households from 1920 to 2016. *Energy Policy, 123*, 41–52. https://doi.org/10.1016/j.enpol.2018.08.041
Timko, J. A., & Kozak, R. A. (2016). The influence of an improved firewood cookstove, Chitetzo mbaula, on tree species preference in Malawi. *Energy for Sustainable Development, 33*, 53–60. https://doi.org/10.1016/j.esd.2016.04.002
Uteau, D., & Donoso, P. (2009). Early individual growth of *Eucryphia cordifolia* and *Laurelia sempervirens* planted under different competition conditions in south-central Chile. *Ciencia E Investigacion Agraria, 36*(1), 85–96.
Vásquez-Lavin, F., Barrientos, M., Castillo, A., Herrera, I., & Ponce, R. (2020). Firewood certification programs: Key attributes and policy implications. *Energy Policy, 137*, Article 111160. https://doi.org/10.1016/j.enpol.2019.111160
Vega-Nieva, D. J., Fernández Lorenzo, M., Ortiz Torres, L., & Corral-Rivas, J. J. (2015). Caracterización bioenergética de los residuos de cosecha de las principales especies forestales del noroeste de España. *Inf. Tecnológica, 26*, 03–12.
Wang, X., & Abdel-Aty, M. (2008). Analysis of left-turn crash injury severity by conflicting pattern using partial proportional odds models. *Accident; Analysis and Prevention, 40*, 1674–1682.
Watson, J. E., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., Thompson, I., Ray, J. C., Murray, K., & Salazar, A. (2018). The exceptional value of intact forest ecosystems. *Nat. Ecol. Evol., 2*, 599–610.
WHO. (2021). Tracking SDG7: The Energy Progress Report. https://www.who.int/multi-media/details/tracking-sdg7-the-energy-progress-report (accessed on July 14, 2022).
Williams, R. (2006). Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *The Stata Journal, 6*, 58–82.
Williams, R. (2016). Understanding and interpreting generalized ordered logit models. *Journal of Mathematical Sociology, 40*, 7–20.
Zúñiga, F., Dec, D., Valle, S. R., Thiers, O., Paulino, L., Martínez, O., … Dörner, J. (2019). The waterlogged volcanic ash soils of southern Chile. A review of the "Ñadi" soils. *CATENA, 173*, 99–113. https://doi.org/10.1016/j.catena.2018.10.003